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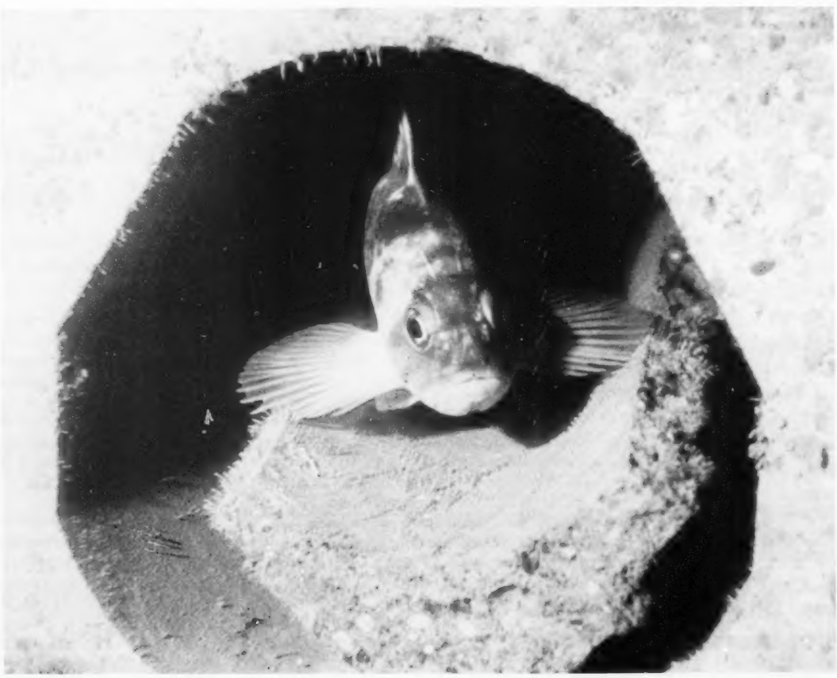
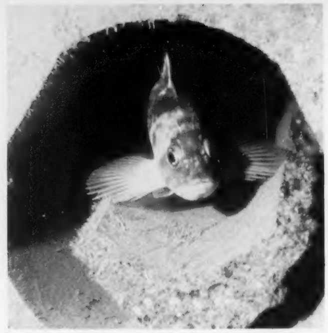
Artificial Reefs and Marine Fisheries Enhancement



Marine Fisheries REVIEW



On the cover: A copper rockfish, *Sebastes caurinus*, photographed on the Gedney Island Boat Anglers Reef in Puget Sound, Wash., by Gregory J. Hueckel, Department of Fisheries, shortly after reef construction.

Articles — *June-July 1982, 44(6-7)*

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Artificial Reefs and Marine Fisheries Enhancement

A Special Issue of the *Marine Fisheries Review*

Preface

Almost a year ago, 23-25 September 1981, the Mid-Atlantic Artificial Reef Conference was held in Atlantic City, N.J. It was cosponsored by the Sea Grant Marine Advisory Service Programs of Delaware, Maryland, New Jersey, New York, and Virginia, in cooperation with the U.S. Bureau of Land Management; Delaware Department of Natural Resources and Environmental Control, Division of Fish and Wildlife; Maryland Department of Natural Resources, Tidewater Administration and Coastal Zone Program; Marine Science Research Center, State University of New York at Stony Brook; National Marine Fisheries Service; and the Virginia Marine Resources Commission, Artificial Reef Program.

The program was designed to address current artificial reef issues and developments through four panels: 1) Legislative and Government programs, 2) temperate reef ecology, 3) industry's role in reef development, and 4) new technologies and designs in reef development. Printed abstracts of those panel sessions are available from the New Jersey Marine Advisory Service, P.O. Box 421, Marmora, N.J. 08223.

Program topics, of course, dealt with marine artificial reef issues and progress of interest and value far beyond the Mid-Atlantic region. This Special Issue of the *Marine Fisheries Review* presents selected papers developed from that conference. I am especially grateful to James D. Murray, Director, New Jersey Marine Advisory Service (currently Director, North Carolina Marine Advisory Service); Daniel J. Sheehy, Aquabio, Inc., Columbia, Md.; and Richard B. Stone, National Marine Fisheries Service, Washington, D.C., for their advice and assistance.

W. Hobart, Editor

Artificial Reefs: Toward a New Era in Fisheries Enhancement?

RICHARD B. STONE

Anglers have used artificial reefs to enhance their fishing opportunities for centuries. Early reef construction in the United States dates back to the mid-1980's (Stone, 1974), while reef construction in Japan started even earlier. Ino (1974) found written evidence suggesting that artificial reefs were already in use in Japan between 1789 and 1801.

Since 1930, Japan has granted subsidies for the construction of various types of reefs. In 1952, Japanese artificial reef research and construction efforts intensified and since then they have continued to expand and improve their program. Artificial reefs are used by the Japanese to improve coastal fisheries. They build both shallow-water reefs (called "tsukiiso") for shellfish and seaweeds and deeper water reefs (called "gyosho") for finfish (Sheehy, 1981). Japanese scientists have evidence that specifically designed shallow water reefs can improve survival and growth of juvenile abalone (Sheehy, 1979).

While the Japanese have been putting millions, and in recent years billions, of dollars into developing sophisticated techniques to create new habitat and increase seafood production (Sheehy, 1982), the United States has pursued a less sophisticated and much more frugal approach. States and local groups have been responsible for most of the reef construction to date, often with limited budgets (Futch, 1981). Scrap materials, because of the low cost, have been used extensively in the United States (Parker et al., 1974), while Japan, and more recently Taiwan (Sheehy, 1981), have put most of their effort into specifically designed and constructed units.

Properly constructed artificial reefs made of scrap materials can enhance rough bottom habitat, provide quality fishing grounds closer to access area, benefit anglers and the economies of shore communities (Buchanan, 1973), and increase total fish biomass within a given area without detracting from biomass potential in this area (Stone et al., 1979). However, the extensive biological and engineering studies conducted by the Japanese, reflected in specifically designed reef material, allow for greater certainty that the reef will stay in place and provide the proper conditions for the particular species desired (Sheehy, 1979).

In recent years, several studies have been initiated in the United States to evaluate techniques that are commonly used in Japan and Taiwan, or to develop new techniques. Speakers at recent artificial reef conferences in Daytona Beach, Fla. (1979), and Atlantic City, N.J. (1981), highlighted these efforts and stressed the need to make reef construction more sophisticated and better organized.

The transfer of advanced Japanese artificial reef technology to the United States was one technique described at both conferences (Sheehy, 1981, 1982) that could provide considerable benefits for both recreational and commercial fisheries. Japanese reef units, made of fiberglass-reinforced plastic, are being tested at locations off Jacksonville and Panama City, Fla. Sheehy's (1981) presentation at the Atlantic City Conference explained how these reefs will be compared with rock reefs built in the same area by the State of Florida to determine biological and cost differences between the two types of reefs.

The use of midwater and surface fish attractors is another fisheries enhancement technique that is receiving considerable attention both in Japan and in the United States. National Marine Fisheries Service experiments in the Gulf of Mexico and off Hawaii in the 1960's and 1970's demonstrated the potential of these devices. Since then, States and U.S. Territories have installed midwater and surface structures and have successful fisheries occurring around them. These units have been particularly productive in the western Pacific. Myatt (1982) described South Carolina's successful venture into the use of midwater fish attractors. In a controlled study, South Carolina biologists found that angler catch per unit of effort for pelagic species was 80.3 percent higher on the fish attractors than on traditional trolling areas.

Two relatively new reef construction techniques that have been developed in the United States involve mineral accretion and the use of coal combustion waste products. Hilbertz (1981) has described the process he has developed to use electrodeposition of minerals naturally present in seawater to build artificial reefs. His process involves the use of direct electrical current through preformed conductive material which precipitates calcium carbonates and magnesium hydroxides from seawater to form a stable substrate.

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The second innovative reef construction technique was described by Woodhead et al. (1982). He reported progress in the use of blocks of coal combustion waste products as reef material. The proper mixture of coal wastes and stabilization additives has been determined so the blocks can be made with standard block making machines. A reef was constructed off Long Island, N.Y., in 1980 with 500 tons of these blocks. It will be monitored for 3-4 years to determine biological and environmental impacts.

Speakers at both recent artificial reef conferences promoted the need to inform the public and managers that the technology is available to enhance fisheries using artificial reefs. Buckley (1982) outlined effective management techniques with artificial reefs now being used in Washington to enhance both boat and pier fisheries. Similar information exists for some other States but frequently remains unpublished and unavailable to the public and the resource manager.

Another factor mentioned at both conferences as being integral to successful reef programs is the need for a stable funding base. Radonski (1982), in his summary statement on the 1981 Mid-Atlantic Artificial Reef Conference, suggested using the receipts from a saltwater fishing license on offshore anglers to fund artificial reef construction. He also discussed other funding sources such as tax incentives to industries that participate in reef construction efforts.

Another possibility that appears to have merit is the use of industry funds in the construction or maintenance of artificial reefs. In some cases, industries may build artificial reefs to mitigate habitat loss from development in estuarine or marine environments, while other industries may be willing to provide funds to maintain structures, such as gas and oil structures, as artificial reefs after their industry application is completed. The funding question will be a key to how rapidly advancements in artificial reef technology occur in the United States.

The papers presented at both of these recent conferences are indicative of the considerable interest by private companies and by local, State, and Federal Governments in improving the resource managers' options for habitat enhancement and fisheries development. They reflect what I believe is the movement toward a new era in fisheries enhancement. In this new era, industry and Government will have to work together to solve the problems of financing reef programs, improving the technology level, and communicating to resource managers the economic and environmental benefits that can result from habitat enhancement with artificial reefs.

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The Use of Designed and Prefabricated Artificial Reefs in the United States

DANIEL J. SHEEHY

Introduction

Artificial reefs have been used to promote fisheries development in both Japan and the United States for at least 200 years. Taiwan and Australia have more recently begun to construct reefs. Although artificial reefs have been built in other countries, the major reef development activities have occurred in these four countries. Japan has a large, well-funded national artificial reef development program. Taiwan had a nationally funded reef research program for several years; reef construction by regional and private groups is now in progress. Neither the United States nor Australia have national reef programs.

Rocks and logs, or scrap materials such as ships, tires, and construction rubble, were used in most of the early U.S. reef-building efforts. Solid waste disposal has been a secondary motive in many American projects, particularly those using tires.

Many of these projects using available or scrap materials proved to be very effective. In Japan and Taiwan, such reefs were used extensively to improve commercial fisheries and aquaculture. In the United States and Australia they are still used to promote recreational fisheries.

However, research conducted in Japan and Taiwan has shown that even though scrap materials and rock can function effectively as artificial reefs when properly handled and sited, appropriate sites for the deployment of these materials are limited. Furthermore, the shapes, size, and long-term physical stability and biological productivity afforded by such materials are less than ideal. Transportation and handling costs, which constitute the major expenditures in the construction of this type of reef, have increased significantly in recent years and the long-term cost effectiveness of such projects has been reduced.

As a result of this situation and an increasing amount of information on optimum design criteria, prefabricated artificial reef units began to be developed in Japan during the early 1950's. Most of this first generation of designed reefs were made from reinforced concrete and were either cubes (Fig. 1) or rectangular boxes with sides of about 1-2 m, hollow interiors, and "windows" on each side, or cylinders of similar dimensions and properties. The larger cubes and boxes, which generally had bigger "windows" and more open space, were often piled in two or three layers to create high profile reefs, while the cylinders and the smaller, less open cubes and boxes were generally not placed in layers. These concrete units proved to be quite effective. In 1954, designed concrete units were designated as the only type of component to be used in government-subsidized regional reef construction projects.

In both Japan and Taiwan, coordinated programs to improve coastal fisheries production have recently been undertaken in response to declines in fisheries production due to the 200-mile extended jurisdiction statutes, increases in fuel prices, and the deleterious effects of coastal development and pollution. Large-scale designed units prefabricated from a number of materials have been used to expand the artificial reef programs in both countries.

The new generation of artificial reef units developed in Japan is manufactured in a wide variety of shapes, sizes, and materials. An assortment of new midwater and floating fish attractors has also been developed and introduced. These new units can be used in a wide range of site conditions not suitable for earlier designs. Many are quite large and are deployed as single units to build very large-scale fish banks. Results of preliminary studies have indicated that in some cases these new units are more

ABSTRACT—Designed and prefabricated artificial reefs have been used with great success to promote fisheries development in Japan and Taiwan, and have been tested on several occasions in the United States. Although efforts in the early 1960's to test Japanese-style reefs in California, New York, and Florida met with problems due to lack of experience with that type of reef, those units which were properly placed proved effective in attracting fish. Pumice concrete shelters designed for lobsters were tested in Rhode Island in the 1970's and were shown to increase significantly the abundance of resident lobsters in areas previously devoid of shelter. The Japanese have recently developed a new generation of large-scale, advanced-technology artificial reefs. To introduce this technology in the United States, Japanese FRP (fiberglass reinforced plastic) reefs have been installed off Florida as part of a demonstration/research project funded by the National Marine Fisheries Service. Their cost-effectiveness will be evaluated by comparing them with concrete culvert reefs.

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cost-effective over the long term than the earlier scrap material or designed units.

Although most artificial reefs in the United States are still built from scrap materials, the availability of some of these (such as liberty ships) has decreased and the cost of transporting, handling, and preparing others has increased in recent years. "White goods" (appliances) and car bodies are no longer considered suitable for reefs because of their high preparation costs and short life expectancy in the water. Both the cost-effectiveness and long-term stability of tire reefs have come into question. Hanni and Mathews (1977) indicated that it is cheaper in Pinellas County, Fla., to dispose of tires in a landfill than to dispose of them at sea by using them for reefs. Problems with tire reefs breaking apart and ending up on tourist beaches or in fishermen's nets have caused several states (i.e., Florida and California) to no longer support the use of tires as an artificial reef material.

Because of the current interest in the United States in installing artificial reefs and the decreasing availability and cost-effectiveness of scrap materials for construction, it is useful to review the past and potential role of designed, prefabricated reefs in American coastal waters.

Figure 1.—Japanese concrete cube reef units (sides = 2 m) being built in Chiba Prefecture, Japan.

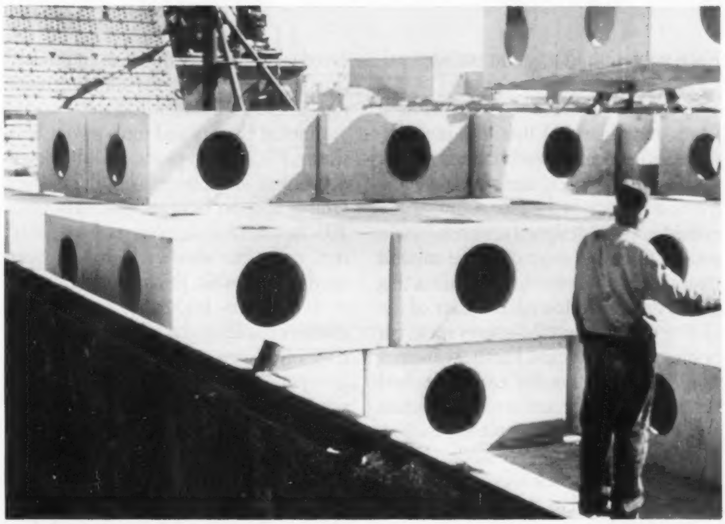

Figure 2.—Japanese-style concrete blocks used in California in the early 1960's. (Photo courtesy of the California Department of Fish and Game.)

Japanese-Style Concrete Reefs

Based on the development of the first reefs designed in Japan during the early 1950's, several states began testing similar structures during the early 1960's. This effort began in California and included Florida and New York. These studies are of interest since the results suggested some of the problems as well as the potential advantages of using such structures.

Early preliminary work by the California Department of Fish and Game (Carlisle et al., 1964) demonstrated that artificial reefs could add productive habitat for recreational fishing.

Further studies, initiated in 1960, compared four types of reef materials in order to determine which would be most suitable for future construction projects in California. Three reefs were built in about 18 m of water on sandy barren ocean bottoms off Malibu, Santa Monica, and Hermosa Beach. Each reef consisted of four subunits composed of the materials under consideration: Streetcars (1/subunit), automobile bodies (14/subunit), designed concrete block shelters(44/subunit) (Fig. 2), and quarry rock (about 333 tons/subunit).

Figure 3.—Concrete units adapted from Japanese-style units prior to placement off Long Island, N.Y., during 1964-65. (Photo courtesy of the New York State Department of Environmental Conservation.)

Each subunit had a volume of approximately 409 m^3.

Extensive observations for several years demonstrated that although differences in effectiveness occurred among the three reef sites, the relative effectiveness of each of the four subunits was consistent. The designed concrete blocks proved to be the most effective subunit material for concentrating and attracting fish. This was followed, in order of declining effectiveness, by quarry rock, car bodies, and streetcars. Further observations indicated that the car bodies and streetcars deteriorated within 3-4 years and became almost completely ineffective. At the time of this study (1963), however, quarry rock was considerably less expensive than the concrete units and was determined to be the most cost-effective material for reef construction in California (Duffy, 1974).

During the late 1960's and early 1970's, a number of tire reefs were constructed in California (Dewees and Gotshall, 1974; Duffy, 1974). Although tires proved to be more durable than car bodies or streetcars and cheaper than quarry rock, problems with binding, puncturing, ballasting, and siting led to eventual dispersal of the reefs and caused tires to be banned as reef-building materials in California (Carlisle[1]).

Pinellas County and the City of Clearwater, Fla., which pioneered the development of artificial reefs in the eastern Gulf of Mexico, built and placed in 1965, 200 Japanese-style concrete "pill box" reef units like those which had been used in California. Each box measured 8 × 4 × 3 feet high and had 18-inch diameter holes in the sides and top. The City of Clearwater placed 75 units in groups of 3-6 on a 2,600 × 500-yard reef site. The remaining 125 units were placed by the county off Indian Rocks Beach.

Due to lack of experience with this type of reef component, inadequate planning, and insufficient control during placement, many of the units ended up scattered over an area believed to cover a half-mile of bottom. Only about 20 of the units remained in the intended area. The rest were so scattered that they cannot be located by fishermen and thus are effectively lost.

[1]Carlisle, J. G. 1980. California Department of Fish and Game, Long Beach. Pers. commun.

A number of concrete units of a design adapted from the Japanese-style units used in California and Florida were placed off southern Long Island, N.Y., during 1964-65. A local contractor used a modified septic tank mold to fabricate the units (Fig. 3).

While available information on this project is incomplete, several problems are known to have made it a failure. The design modifications resulted in apparently extensive damage to the units during handling and placement on the barge used to tow them to the deployment site. Because of further problems resulting from poor weather and lack of proper planning, the location of the placement area was not recorded. The units remain unlocated and unevaluated.

As this brief review indicates, the major problems encountered in attempts to use Japanese-style concrete units in the United States arose from improper design, handling, siting, and placement. (It should be noted, however, that similar problems due to similar causes were not unknown in Japan when designed concrete units were first put into use.) Except in California, where considerable experience in building large-scale reefs had been developed, some or all of the units were lost due to improper placement. Attempts in New York to adapt existing septic tank molds for fabrication of the reef units resulted in structural degradation and losses during handling even prior to actual placement.

In California, where the units were placed relatively properly, they proved to be the most effective form of reef unit; they were 18 percent more effective than quarry rock. Despite the placement problems in Florida, the 20 units which were not lost have been observed by divers for more than 17 years and continue to provide very effective habitat for grouper, sheepshead, and a variety of other species. A recent dive on this reef in December 1981 indicated that these units are completely intact, stable, and very productive (Fig. 4).

Although 20 years ago the California Department of Fish and Game suggested that, at least for the term of their study, quarry rock was more cost-effective than the otherwise more effective concrete units, cost differences may not be such a

significant factor today, especially over a long-term period. This is particularly true in light of the recent advances in reef design, siting, and placement techniques which have been made in Japan and confirmed in Taiwan.

In 1963 the cost of 1,000 tons of quarry rock delivered in place in Santa Monica Bay cost $6,000 ($6/ton). A similar volume of concrete units cost $11,000 at that time. A recent project in California which involved the placement of eight rock-pile reefs off San Onofre cost about $250,000 (10,000 tons at $25/ton), more than four times the 1963 cost. Although the new Japanese-designed reefs may still be somewhat more expensive per unit volume than rock, they may also be more effective on a long-term basis. Furthermore, volumetric comparisons may not be valid for measuring effectiveness.

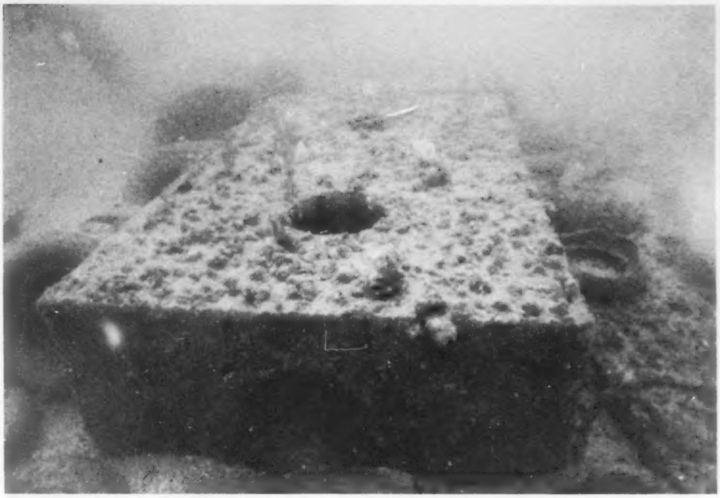

Figure 4.—Japanese-style "pill box" reef placed off Clearwater, Fla., in 1965 and photographed in 1981.

Lobster Reefs

Designed artificial shelters have also been used to promote or expand fishing areas for commercially important invertebrates and seaweeds. Although most of this work has been done in east Asia, several studies have been conducted in the United States with the northern lobster, *Homarus americanus.*

A number of researchers (Briggs and Zawacki, 1974; Scarratt, 1973; Stewart, 1970) have suggested that in some areas shelter is a limiting factor in the distribution and abundance of nearshore lobsters. The addition of shelter in areas previously devoid of cover or substrate suitable for burrowing has been shown to increase the abundance of resident lobsters. Observations have also indicated that extensive growth of encrusting organisms on artificial substrates serves as a source of food for the lobsters (Sheehy, 1976; Alfiere, 1975; Weiss, 1970).

Several types of designed artificial shelters for lobsters were fabricated from pumice concrete as part of a series of studies begun in Rhode Island during 1971. Preliminary studies with a single chamber unit (Fig. 5A) were conducted at several shallow sites off Point Judith, R.I., to determine if the carrying capacity for lobster in sand bottom areas could be increased.

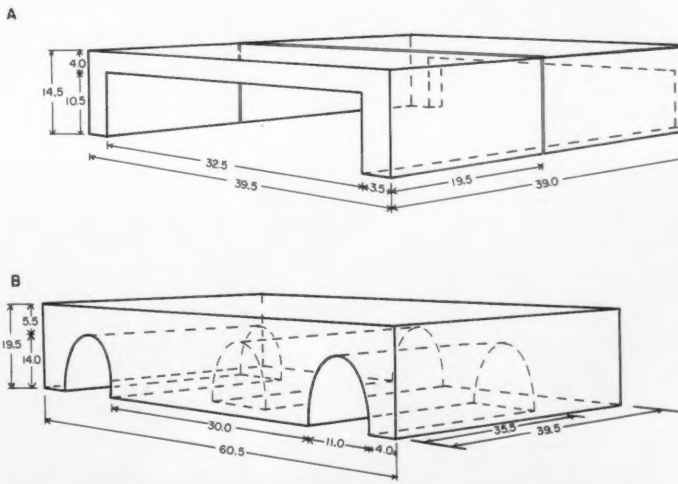

Figure 5.—Artificial shelters fabricated from pumice concrete in Rhode Island: A = single-chamber (2-piece) unit and B = triple-chamber unit.

Results indicated that the addition of lobster shelters significantly increased resident lobster populations (Fig. 6). Observed lobster abundances were equal to or greater than those observed on good natural grounds. In addition, results indicated that shelter spacing had a significant effect on occupancy by lobsters

Figure 6.—Lobster occupying two-piece single-chamber shelter. Extensive mussel growth on the shelter surface.

Figure 7.—Juvenile lobsters and crabs, *Cancer borealus,* found in triple-chamber unit being examined by diver.

and that shelter orientation, with respect to predominant wave and current directions, affected the stability of the shelters on the bottom. Interactions between lobster size and shelter spacing intervals were also suggested (Sheehy, 1976).

Two-piece shelters used in the initial study proved to be unstable during severe wave conditions and current velocities. Shelter loss was due both to subsidence resulting from scour and to overturning and separation of sections by wave action. Shelter orientation had some influence on the rate of loss; however, the design was considered unsuitable for all but experimental purposes (Sheehy, 1976).

A second pilot study which compared single- and triple-chamber shelter units affording approximately the same available shelter volume (Fig. 5B) demonstrated that triple-chamber units had greater overall use and supported larger populations due to the compartmentalization. During this study, all benthic life stages of the lobster were observed on and within the reefs. Significant seasonal variations in both lobster and other populations (Fig. 7) occupying the reefs were also observed (Sheehy, 1976).

Although triple-chamber shelters were more stable due to increased weight and bottom surface area, they proved more difficult for divers to handle and space. Both laboratory and field studies were conducted by Jones (1974) to develop a more stable design and a basic computer simulation program to evaluate these units under various combinations of substrate and oceanographic conditions. This information, as well as fabrication costs and logistic considerations, was used to design a new and smaller single-chamber unit (Fig. 8, 9) to conduct larger scale controlled tests at six sites in Rhode Island.

Each of these six reefs (Fig. 10) was monitored bimonthly by divers for a year. The three most stable reefs were monitored for a second year as part of a tagging program. During each survey, divers carefully monitored the position, size, sex, molt condition, and claw number and size of each lobster (Fig. 11). Multidimensional contingency table analysis was used to examine the interaction of variables in the lobster abun-

dance and distribution within the reef (Sheehy, 1977).

Results from this study confirmed and expanded on the prior studies by again demonstrating that the addition of artificial shelters in areas devoid of natural shelter or substrate suitable for burrowing can significantly increase the abundance of lobsters. However, the results also confirmed earlier statements by Scarratt (1973) and others that suitable sites for lobster reefs are limited. A careful examination of all relevant site factors, particularly maximum wave and current conditions, substrate, and available food resources, should be made prior to future construction.

Unit artificial shelters may offer a viable alternative to the use of natural rock or scrap material in the construction of large-scale reefs for lobsters. Although such designed shelters can be used to create new habitat for lobster, a careful analysis of all cost factors should be made before commercial scale reefs are constructed. If some of the legal restraints to "extensive aquaculture" are removed, additional uses for such reefs may soon develop.

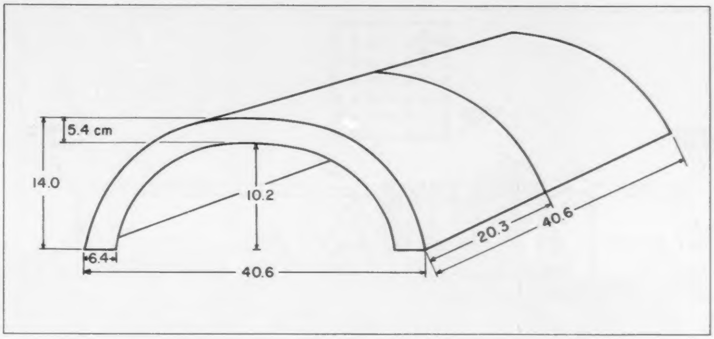

Figure 8.—Smaller single-chamber unit fabricated from pumice concrete (dimensions in centimeters).

Figure 9.—A lobster occupies a smaller single-chamber unit with extensive macroalgae growth on shelter surface.

Japanese Fiberglass Reinforced Plastic (FRP) Reefs in Florida

The new artificial reef technology developed in Japan and Taiwan has been described (Sheehy, 1979, 1981; Chang[2]). These large-scale structures represent a new generation of artificial reefs which are designed, prefabricated, and installed to promote commercial fisheries, to rehabilitate areas adversely impacted by human activities such as pollution and coastal development, and to serve as part of extensive aquacultural projects (Sheehy and Vik, 1981). They are the result of considerable research and development. To receive approval for use in projects funded by the Japanese government, reefs must meet certain standards for strength and stability and must be judged to have a minimum useful life span (without structural degradation) of 30 years when properly built, handled, and sited.

Aquabio, Inc.[3], a marine research and development group, has recently initiated a project to introduce this new Japanese technology in the United States and

[2]Chang, K.-H. 1981. Taiwan's artificial reef research program. Presented at the Mid-Atlantic Artificial Reef Conference, Atlantic City, N.J. Institute of Zoology, Academia Sinica, Taipei, Taiwan.

[3]Mention of trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

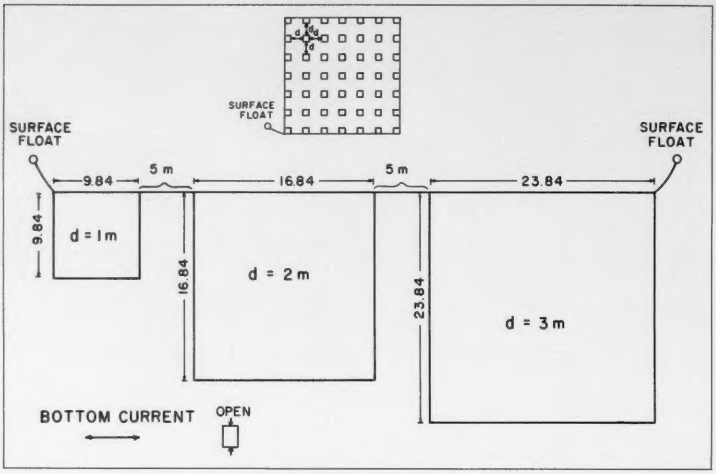

Figure 10.—Placement configuration of individual reefs (spacing intervals in meters). Inset: Expanded view of an individual matrix; "d" is the intersheltcr distance.

determine which aspects have the most potential for application in American fisheries development. An important part of this project, funded principally by the National Marine Fisheries Service (NMFS), involves a demonstration and evaluation of Japanese artificial reefs in U.S. coastal waters.

To determine which types of reefs have the most potential for immediate use in the United States and would therefore be most appropriate for the demonstration, the stability, strength, life expectancy, and biological effectiveness of a number of manufactured reef units commercially available in Japan were evaluated. Design flexibility and costs associated with construction, transportation, and placement were also considered.

FRP units, manufactured by Asahi Chemical Industry Co., Ltd., were selected as most suitable for small-scale testing and evaluation off the Florida coast. The reef components were readily shipable from Japan, capable of being assembled with relatively unskilled labor and minimal equipment, and could be placed without the use of large cranes and barges. In addition, these units could be built in a variety of configurations, and this could be designed for fish, shellfish, and macroalgae.

Reef components and materials manufactured in Japan were sent by container ship to the United States, erected, and placed off Panama City and Jacksonville,

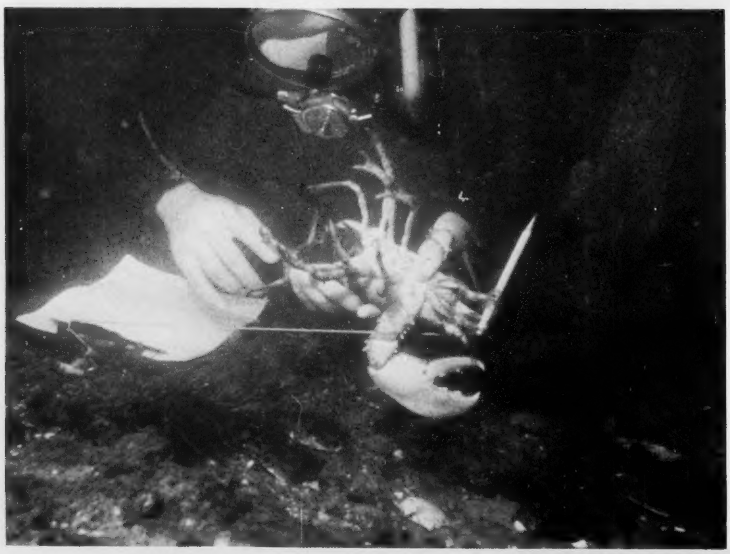

Figure 11.—Diver examining egg-bearing female lobster while monitoring reef.

Fla., during August and September 1981. Reef components, essential materials, and engineering services were donated by Asahi. The reef units were built and placed by students, graduates, and staff from the Panama City and Jacksonville Marine Institutes with technical supervision by Asahi and Aquabio. Some financial and administrative support to assist with construction of the Japanese units and a concrete culvert reef placed at each site for comparative purposes were provided by the Florida Department of Natural Resources. Assistance with selection of specific sites was provided by the Jacksonville Offshore Sport Fishing Club and the Marine Institutes.

As previously noted, many of the problems encountered in the earlier use of Japanese-style reefs in the United States were due to improper design, siting, handling, and placement. To gain the full benefits of using Japanese reefs in this demonstration project, Aquabio made every effort to ensure that the units were built exactly according to the manufacturer's directions, were handled properly to avoid damage, and were placed correctly and accurately on predesignated, carefully selected sites. This conservative approach, along with the diligent work of the Marine Institute students, graduates, and staff, resulted in the proper placement of undamaged units at the specified permitted sites.

Jacksonville and Panama City were chosen as sites for this project for a variety of oceanographic and logistic reasons, as well as criteria recommended by the manufacturer. Both represent fairly typical substrate types and water depths for reef construction along both coasts of Florida. Jacksonville is relatively typical of areas along the southeast Atlantic coast in terms of slope and bottom type. Panama City, while not really typical of the entire Gulf area, is representative of the northwest coast of Florida and is an area which has potential need for further reef development. Panama City also provides relatively reliable visibility for detailed underwater observations. A maximum depth limit of 80 feet was set in order to provide sufficient no-decompression bottom time for divers to conduct surveys and recover sample plates and instruments.

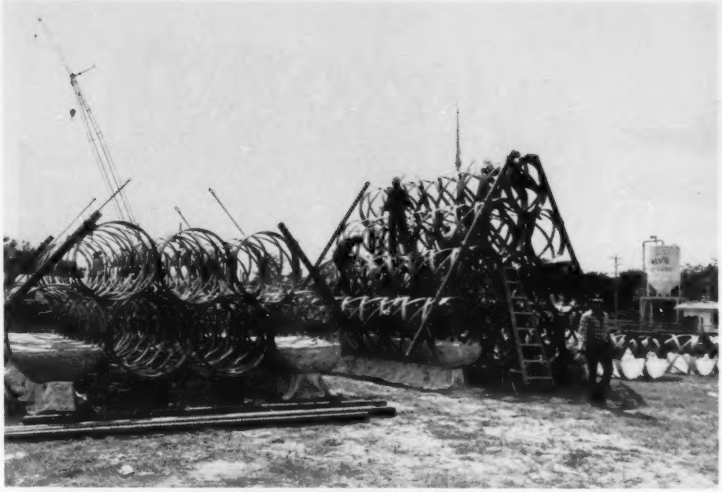

Figure 12.—Three types of FRP units built in Jacksonville, Fla. Concrete ballast has been placed in lower cylinders of largest unit.

Sites were also screened to ensure long-term reef stability. Prior to selection, available oceanographic data and estimates of significant and maximum wave heights and periods and maximum current velocities were collected along with substrate data. Using stability calculation equations developed in Japan, the stability of various reef unit configurations was evaluated. Since these units have been extensively tested in Japan under a variety of conditions, field data confirming these calculations was available.

Both Jacksonville and Panama City have had artificial reef programs for some time and a number of other reefs of different types are available for comparative purposes. The Jacksonville Offshore Sport Fishing Club has built reefs off Jacksonville for over 20 years and has collected considerable information on species caught in the reefs and their seasonal variation. Likewise, the Panama City Marine Institute has built a variety of reefs off Panama City; recent field studies on these reefs conducted by researchers from Texas A&M University will provide useful comparative information.

The specific sites selected in both areas had flat, coarse sand bottoms devoid of any natural relief. Preplacement surveys conducted at each site indicated a relatively low abundance of fish. Adjacent areas with similar bottom characteristics were selected as control sites for future surveys.

The reef components and materials arrived through the port of Savannah, Ga., and were trucked to staging areas in Panama City and Jacksonville. The principal components were cylinders 5 m long and between 1.0 and 1.2 m in diameter fabricated from strips of FRP (Fig. 12). The slight variations in the diameters of the cylinders permitted the components to be nested during shipping to reduce space requirements. Additional structural components, such as guard bars and anchor piles, were made from heavy-wall FRP pipe sections.

Although the FRP reefs are not difficult to build, proper supervision and quality control are essential in all aspects of the building and placement. The erection process took about 2½ days at each site, with several slight delays due to material variations, equipment adjustments, and rain. The work crew consisted of five students or graduates and two supervisors.

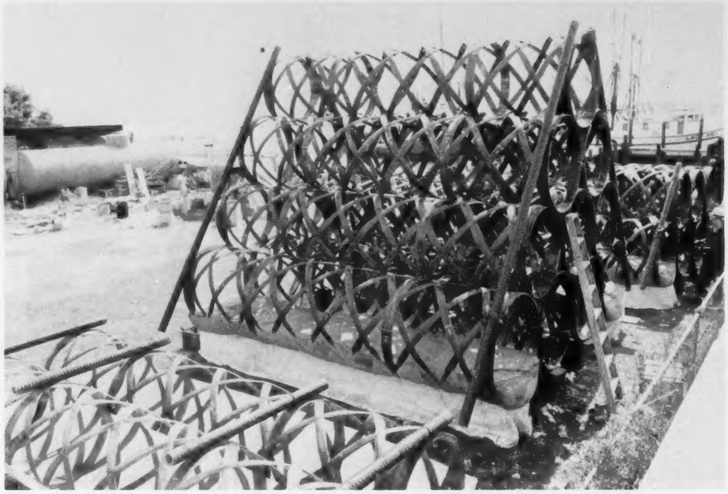

Figure 13.—The 10- and 7-cylinder units during construction in Jacksonville, Fla.

Figure 14.—Workers fiberglassing all connecting points.

After being unpacked, the units were sized, placed in position on stands, and fastened together with heavy wire (Fig. 13). FRP guard bars, designed to add structural support and reduce damage from towed fishing gear, and steel lifting eyes used for hoisting the units into the water were also wired into place. All connections were then fiberglassed with impregnated twisted roving wound on a hand machine designed for this purpose (Fig. 14).

Fabric bags used for casting the concrete ballast were also temporarily attached with steel wire to the appropriate number of bottom cylinders. The number to be ballasted and the amount of ballast per cylinder are adjusted to site-specific oceanographic conditions. Anchor piles, used to prevent the reef unit from slipping on the sea bottom, were placed through the fabric bags; specially fabricated reinforcing rod frames and connecting rods and pieces were then placed in the ballast cylinders. Quick setting, early-strength concrete was poured, smoothed, and permitted to harden.

Airbags designed to fit into the lower cylinders were inserted. The reusable airbags permit these units to be floated and towed to the placement site, thus eliminating the need for a barge or floating crane required by all other large-scale Japanese reef units. Nylon covers, FRP sheeting, and linoleum were placed around the airbags to reduce abrasion by the concrete and FRP strips. The bags were then inflated, inspected for leaks, and secured in place (Fig. 15).

Tow bridles and lines were attached to both units and a crane equipped with a special spreader bar was used to pick up the units and place them into the water. The units were temporarily secured at dockside while lines were rearranged and the tow line was secured to the tow vessel. A vessel of about 5 tons is generally sufficient to tow the units in tandem; however, a small tug was used in Panama City and a large charter boat was used in Jacksonville for safety and to carry additional observers.

The units were towed (Fig. 16) to the permitted site where temporary buoys had been placed earlier. On site, the two units were detached and maneuvered into position by a small outboard vessel. The stern of each unit was anchored and the unit was oriented by the outboard. The airbags were vented, causing the reefs to sink (Fig. 17). Dive teams recovered the lines and inspected the

units. The airbags and nylon liners were recovered by the tow vessel.

No damage from impact on the bottom or other causes was observed at either site. Units rested on the bottom and were supported by the anchor piles, with about 5-12 cm between the bottom of the cylinders and the seabed.

A 10-cylinder unit and a smaller unit (9-cylinder unit in Panama City and a 7-cylinder unit in Jacksonville) were placed at each site. This variation was planned as part of a long-term stability test to determine if theoretical calculations concerning stability in "worst case" conditions such as a hurricane were correct.

As part of the project, Aquabio is currently conducting a 1-year research program at both sites funded by an NMFS grant. This program includes surveys of benthic, encrusting, and fish populations, as well as primary productivity and oceanographic studies. The research effort will evaluate the Japanese FRP reefs, the concrete culvert reefs of approximately equal volume constructed at each site, and control areas in terms of fish abundance and distribution, and benthic and encrusting community development (Fig. 18). At the end of the monitoring period, a cost-effectiveness comparison between the FRP and the culvert reefs will be made.

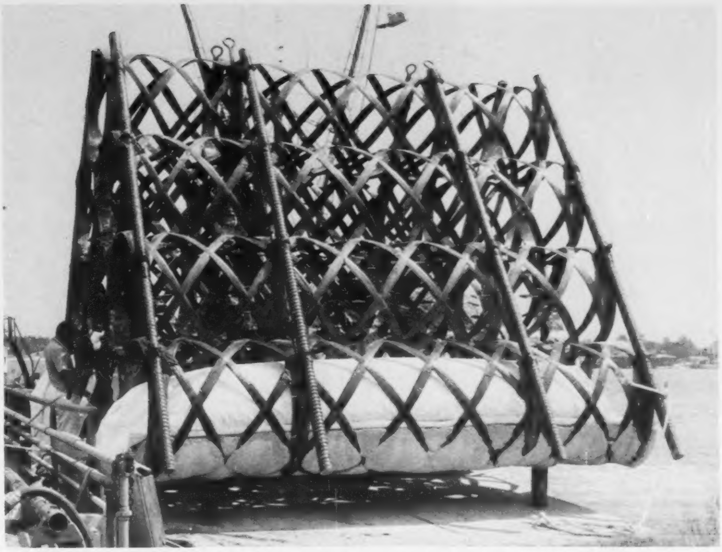

Figure 15.—Reef unit on dock. Airbags are being checked and inflated. The unit is standing on anchor piles.

Figure 16.—Reef units being towed to site off Jacksonville, Fla.

Potential Uses for Designed Reefs in the United States

Designed and prefabricated reefs offer a means of improving and managing coastal marine areas. The design flexibility permits the construction of stable, durable units which can be directed at specific species or even life stages. This flexibility and relative permanence make such reefs particularly suited for enhancing heavily used recreational fishing areas, increasing the production of commercial fisheries, serving as part of compensation/mitigation projects, and developing extensive aquaculture programs.

Although construction of artificial reefs to promote recreational fishing has a long history in the United States (Stone, 1972), very few reefs have been used extensively for commercial fishing, with the exception of those used by charter boat fisherman. It is possible, however, that commercial use may become more common in the future. Many U.S. commercial fisheries could benefit from the application of advanced artificial reef technology. Japan, the premier fishing

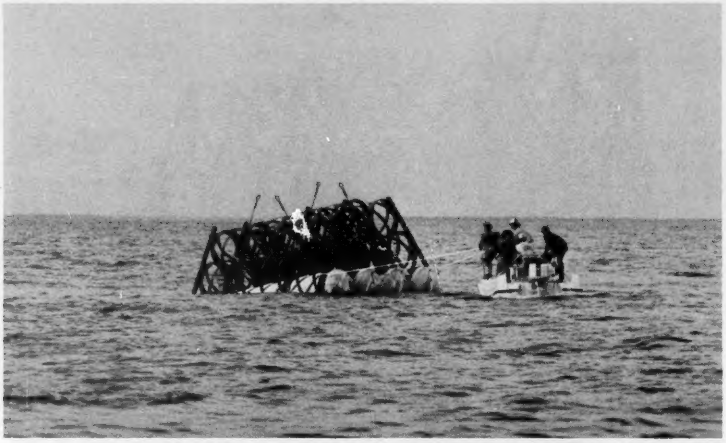

Figure 17.—Reef unit being sunk on site off Jacksonville, Fla.

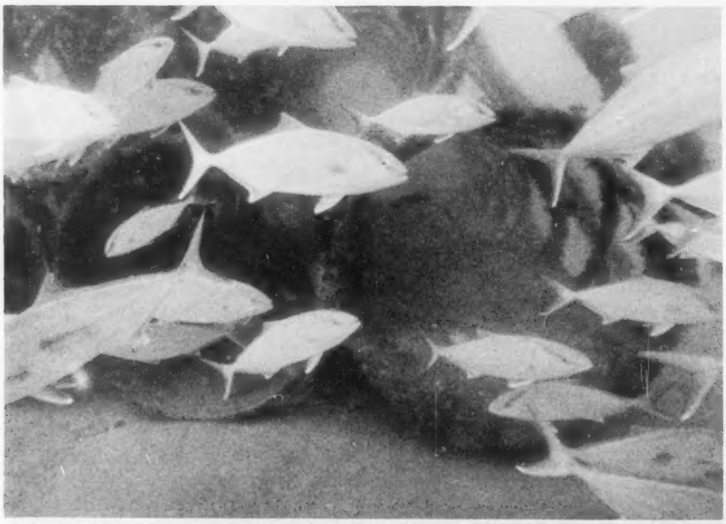

Figure 18.—FRP reef off Panama City, Fla., photographed during the November survey.

nation, has relied on designed units for almost 30 years.

The use of reefs as a means of compensation or mitigation for various coastal development projects has been common in Japan for some time but is relatively recent in the United States. The potential of this application has been shown by recent efforts in California described by Grove (1982). Other coastal and estuarine areas subjected to some form of environmental or fishery loss may find that artificial reefs can contribute to comprehensive mitigation or compensation programs or plans. Many such projects are in high energy coastal or restricted estuarine environments where dredging, filling for land reclamation, power plant effluents, and other disturbances can have significant impacts. It is important that stable, aesthetically acceptable, effective, and relatively permanent structures be used in such compensation or mitigation projects since they should last as long as the impact for which they are compensating or mitigating. Many of these areas are subject to heavy recreational fishing; since suitable available space is limited to multiple uses and physical or biological restraints, it is essential that the most effective type of unit be used.

Artificial reefs have been used quite successfully to improve coastal aquaculture in both Japan and Taiwan. This use has been particularly effective with some of the mobile invertebrates and macroalgae species. Designed reefs are also used as nursery and spawning areas for fish. Some of these reefs are used to augment natural nursery areas or in conjunction with stocking programs. The only real marine culture reefs which have been used commercially in the United States are oyster reefs; however, there is significant potential for a variety of both marine and anadromous fish as well as invertebrates such as the abalone and lobster (*Homarus*), and macroalgae such as *Macrocystis*.

Although there are differences between east Asian and North American fisheries, the advances resulting from the extensive research and development in Japan and Taiwan can be modified for application in the United States. The design and site selection criteria developed for prefabricated units can also be applied to scrap material reefs to help improve their effectiveness and stability. This criteria could be especially valuable to the continued use of tires, concrete rubble, ships, and the expanded use of surplus oil and gas production rigs (Sheehy, 1982).

As the Japanese have demonstrated, the habitat improvement techniques

made possible by designed and fabricated artificial reefs have enormous potential for expanding coastal resources and rehabilitating areas adversely impacted by human activities. The possible applications of this advanced reef technology in the United States should continue to be investigated.

Acknowledgments

The demonstration of Japanese FRP reef technology in Florida was the result of a cooperative effort between the National Marine Fisheries Service, Asahi Chemical Industries Co., Ltd., and Aquabio, Inc., with additional support provided by the Florida Department of Natural Resources, the Associated Marine Institutes, Inc., and the Jacksonville Offshore Sport Fishing Club. I wish to thank all the people from these groups who helped with the project, and give particular acknowledgment to Richard B. Stone of NMFS; S. Inaba, Y. Sakata, and K. Kikusawa of Asahi Chemical Industries; Lonnie Ryder of the Florida Department of Natural Resources; and Tony Traviesa, Fred Kremer, and O. B. Stander of the Associated Marine Institutes. Special thanks are also due to the students, graduates, and staff at the Panama City and Jacksonville Marine Institutes who were involved with construction and placement of the reefs, and to the members of the Jacksonville Offshore Sport Fishing Club who provided assistance throughout all stages of the project. Photographs, unless otherwise credited, were made by the author.

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The Coal-Waste Artificial Reef Program (C-WARP): A New Resource Potential for Fishing Reef Construction

PETER M. J. WOODHEAD, JEFFREY H. PARKER, and IVER W. DUEDALL

Introduction

Artificial reefs undoubtedly work: They form a settlement base for biological colonization and growth, and their crevices and surfaces provide cover and habitat for many organisms including fishes, crabs, and lobsters. They have proven success in attracting marine life, and in enhancing the local marine environment to improve recreational fishing significantly.

Artificial reefs are popular with sport fishermen; angler's clubs and civic groups have been active in reef construction, frequently with cooperation from local and state agencies.

While it is well known that reefs provide benefits to recreational fishing, they also provide more direct economic benefits. A recent study by the South Carolina Division of Marine Resources indicated that recreational fishing on the South Carolina artificial reefs in 1977 accounted for local expenditures of about $5 million in the coastal communities, although through "multiplier effects" the total expenditures within the State were estimated at about $10 million. Reef building may therefore be a desirable activity for marine habitat improvement, which provides tangible biological, recreational, and economic benefits to local communities.

Unfortunately, funding for reef construction is currently an important obstacle. Although materials for reef construction are frequently donated, the costs are high for labor and for hiring cranes and barges to place the materials in the ocean. Because the benefits from a reef are distributed widely in the community no single group may wish to fund the project. At the same time there is taxpayer resistance to spending public funds for privately enjoyed recreational activities. In recent years the lack of adequate funds has prohibited new reef building in important candidate areas such as the New York Bight, which are subject to intense sport fishing and would benefit from habitat improvement (Jensen, 1975).

A potentially important new resource for the construction of fishing reefs may be provided from by-products of coal combustion, as electricity generating stations increasingly convert from burning oil to coal (Woodhead et al., 1981). The waste materials from coal combustion, produced in large volumes daily, consist of a flue-gas desulfurization (FGD) sludge and fly ash, both of which require disposal. For power plants near the coast, marine disposal might be an option, but uncontrolled dumping of untreated scrubber sludge or fly ash in the sea would have deleterious environmental effects. However, industry has developed a system to treat these wastes with additives and enable cementitious reactions to occur. The mix becomes a stable material that can be formed into blocks and cured to hard solids. The stabilization reactions which take place during hard block formation are very similar to pozzolanic reactions which occur in curing of concrete.

We are assessing the feasibility of using such stabilized, solid blocks of coal combustion by-products as potential construction material for artificial fishing reef building. If the blocks prove suitable and have no adverse effects on the marine environment, the major expense of reef construction—handling and transportation — may be encumbered in the waste disposal costs.

Early Studies

The coal-waste artificial reef program (C-WARP) began in 1976 with various laboratory studies of the interactions of test blocks made from coal waste materials in seawater systems. Special attention was given to the leaching of major

ABSTRACT—The feasibility of using solid blocks of waste material from coal-fired power plants for underwater construction, including building artificial fishing reefs, is being tested. On 12 September 1980, a 500-ton demonstration reef, consisting of 15,000 solid blocks of stabilized fly ash and flue-gas desulfurization (scrubber) sludge from coal-burning power stations, was constructed in the Atlantic Ocean off Long Island, N.Y. Biological settlement and epifaunal colonization are already well established. Fishes inhabit the reef at high population densities, and crabs and lobsters have begun to immigrate. Laboratory and sea experiments over the past 5 years suggest that stabilized coal waste blocks may be environmentally acceptable in the ocean.

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chemical components and of heavy metals from the blocks (Seligman and Duedall, 1979). Bioassays of seawater elutriates were made with cultures of a sensitive marine diatom, *Thalassiosira pseudonana*, to determine whether there were any toxic effects. Assay methods recommended by the U.S. Environmental Protection Agency and the U.S. Army Corps of Engineers were followed. Significant leaching of potentially toxic elements did not occur and inhibitory effects on plant growth and photosynthesis were not observed in the elutriates. Physical tests showed that the blocks did not bread down in seawater but remained solid, dense, and strong.

Following the positive results of the laboratory investigations, small-scale field investigations were conducted during 1977-78 and 1978-79 with arrays of blocks of stabilized materials set out on the bottom of a shallow embayment of Long Island Sound. The results of these early series of field investigations also suggested that the coal combustion waste materials, when stabilized into solid blocks, are acceptable in the marine environment (Roethel et al., 1980). We saw no adverse environmental effects. The physical integrity of the blocks was maintained over exposure periods of 1 and 2 years at sea and some increases in block strength during exposure were measured. The materials were found to provide suitable substrates for biological colonization and overgrowth by encrusting marine organisms which are characteristic of artificial reefs. Fishes became associated with these early arrays of test blocks — toadfish, *Opsanus tau*, soon spawned and attached their eggs to the block surfaces, some fish species fed upon the encrusting epifaunal growths, and others took up residence in the nooks and crannies between blocks.

Blocks and Reef Building

The next phase of the C-WARP was to build a demonstration, pilot-scale reef of waste blocks in the Atlantic Ocean. The program required that the demonstration reef would be studied for 3 years by a multidisciplinary team of oceanographers, fishery biologists, and engineers to provide data to assess its biological, physical, and chemical interactions with the marine environment.

Our initial laboratory and field studies had been mainly made on stabilized wastes formed into small numbers of cubic-foot blocks which were individually mixed and formed by hand. For the demonstration reef, which required thousands of blocks, such laborious, slow fabrication methods were unacceptable as well as expensive and new methods had to be adopted. In collaboration with the Besser Company[1], Alpena, Mich., we developed techniques to process power plant wastes with the machines and equipment used by the concrete industry. The new techniques were successfully transferred to a commercial concrete block factory and 500 tons of power plant FGD scrubber sludge and fly ash were used to manufacture large numbers of solid blocks of the stabilized materials, $20 \times 20 \times 40$ cm ($8 \times 8 \times 16$ inches). The blocks were formed out of two coal waste mixes from different sources, having fly ash to scrubber sludge ratios of 4:1 and 1:1, respectively. Concrete blocks of the same size were used for controls.

The 500 tons of factory fabricated blocks were cured in kilns to achieve compressive strengths of about 500 psi, which allowed stacking for transport. They were trucked to a terminal on the Hudson River estuary and loaded on a barge fitted with bottom opening doors (Fig. 1). On 12 September 1980 the barge released the blocks at the project site (Fig. 2, 3) to build the Atlantic demonstration reef consisting of more than 15,000 blocks of stabilized coal waste.

Our field studies on this demonstration reef and its interactions with the ocean are in their second year and prospects for utilizing coal waste materials as a resource for reef construction continue to look promising. We are also making comparisons between the populations of colonizing invertebrates and of fishes on our reef, and the populations that we find on the long established Fire Island artificial reef system, described by Jensen (1975), which is nearby.

[1]Mention of trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

Study Area Description

The demonstration coal waste block reef is located south of Long Island, N.Y., at long. 72°13'W, lat. 40°35.8'N; 5.8 miles ESE of Fire Island Inlet. The 15,000 blocks lie on a sandy seabed at 20 m depth, and form one continuous structure approximately 77 m (250 feet) long, 14-18 m (45-70 feet) wide, and 1 to 2 m (3-6 feet) high. The seabed sediments in the vicinity consist generally of medium to coarse light brown quartz sand with grains from 0.1 to 2 mm diameter; there are also overlying patches of dark gray mud up to 1 cm thick scattered in the area. The macrobenthic infauna has been sampled frequently and is characteristic of the general inshore region of the New York Bight.

Repeated oceanographic surveys have been made at and near the project site to characterize the physical and chemical properties of the water column, nutrient concentrations, suspended particulates, current speed and direction, etc. Sea temperatures range from maxima in August of 23°C at the surface and about 14°C at the bottom, falling to a winter minimum of 0°-1°C in February, when the water column is completely mixed. Salinities are typical of the coastal seas and range from 30 to 34‰, although periodic low salinity inputs from Great South Bay are not uncommon. Close to the seabed, turbidity is relatively high, sighting distances often being only 1 or 2 m and after storms may be reduced to zero visibility. The results of the initial oceanographic surveys of the site have been published (Woodhead and Duedall, 1979) and further surveys have been completed to describe the seasonal cycles of oceanographic change.

Physical and Chemical Results

Long-term laboratory experiments have confirmed several trends in the physical effects of seawater immersion on test blocks. Block densities were found to increase throughout continued exposure to seawater. Block strengths also showed increases after immersion. Such extended nondestructive studies were made possible by the use of ultrasonic test procedures developed by engineers in the program. Positive cor-

Figure 1.—Loading "pocket" barge with eight compartments fitted with bottom opening doors.

Figure 2.—Barge filled with 15,000 blocks being maneuvered for release at project site.

Figure 3.—Blocks on sea bed. Bottom water at site characteristically contains particulates and mucous strings.

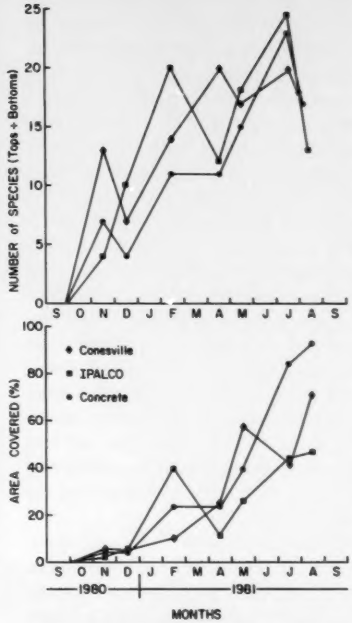

Figure 4.—Progress of epifaunal colonization on reef blocks. Top, number of colonizing species; bottom, area covered.

relations were developed between the velocity of sound transmitted through the blocks and compressive strength. The ultrasonic method is now used by divers at sea for nondestructive, repetitive testing of reef blocks in situ.

A variety of coal wastes which were screened were analyzed by a number of different techniques for elemental composition and mineralogy. The changes which occur with curing and during prolonged exposure in the sea are now being studied. Long term leaching experiments in seawater yielded leaching rates for major block components, such as calcium and sulfate. These data have been used to construct a model for the diffusion with time of major components from the blocks into seawater (Duedall et al., 1982). Such a model may be important in estimating the life of the blocks in the ocean, based on the rates of loss of major components which we measure in blocks which we periodically bring back from the reef.

Epifaunal Colonization

Biological settlement and colonization on the reef blocks have taken place continuously since the reef was first established. Test blocks have been removed from the site every 4-6 weeks for laboratory analysis, and a steady increase in the biological cover of block surfaces was recorded. Due to low light penetration at the site, plants did not settle and grow but overgrowth by animals on the top surfaces of the blocks after 1 year in the sea was 51 percent and 41 percent of the surface area on the 4:1 and 1:1 waste blocks, respectively. Colonization on bottom surfaces was rather more dense (probably because the bottoms had protection from sedimentation), the equivalent percent cover being 75, 70, and 45, respectively (Fig. 4). Generally the degree of settlement on the concrete and on the 4:1 waste were similar during the first year, but settlement on the 1:1 coal waste was slower or less successful. Concrete surfaces were harder than either coal waste and the immediate surficial layer of the 1:1 mix in particular was soft or slick. This probably influenced surface selection by some epibenthic larvae and may also have effected the long-term adhesion of organisms with upright, branching growth forms, such as hydroids and bryozoans.

The community of epifaunal organisms growing on the blocks after a year's exposure at sea was diverse; the predominant organisms were stalked ciliates, polychaete worms, mussels, barnacles, and feathery growths of hydroids and bryozoans. In August 1981, 16 different species were found on concrete blocks compared with 19 and 13 species on the 4:1 and 1:1 mix experimental

blocks. In the following month, September, after completion of 1 year in the sea, there was a small reduction in the number of species recorded on the coal waste mixes to 14 and 10 species, respectively, compared with 16 on the concrete controls. The communities on all blocks had similar species composition although the percentage representation of some species changed significantly with block type. In particular, quite marked differences were found consistently over most of the year for the polychaete tube worm, *Polydora socialis*, which occurred commonly on the blocks of coal waste but was only sparsely represented or absent from concrete. *Polydora* was able to bore superficially into the outer layer of the coal waste to build tubes, but not into the concrete, which may account for its success in becoming established on the coal waste blocks.

Epifaunal colonization and overgrowth of the blocks had been more rapid in the early field experiments made in a shallow embayment of Long Island Sound, with good light penetration. Marine plants grew profusely on these shallow blocks and within less than a year epifaunal development on the different types of blocks had converged so that the communities were not distinguishable (Roethel et al., 1980). The differences which we have found at the Atlantic project site, particularly the lower rate of colonization, may be attributed to the low levels of light penetration. Plants do not grow and the energy inputs to the fauna are probably less allowing only slow growth and community development.

Toxic Potentials

These waste materials contain very small amounts of potentially harmful elements such as cadmium, arsenic, lead, mercury, and selenium. Released into the environment, these components of combustion wastes might be expected to exert toxic effects. However, initial laboratory bioassays made on seawater elutriates from finely powdered block material failed to demonstrate inhibitory effects on the growth and photosynthesis of a marine diatom, nor were the survival and normal development of sensitive eggs and larvae of winter flounder, *Pseudopleuronectes americanus*, affected (Woodhead and Duedall, 1979).

Bioaccumulation of heavy metals through marine foodwebs is an important environmental concern and organisms exposed to these wastes for long periods have therefore been analyzed for uptake of heavy metals. A series of repeated collections of epifaunal biomass from the blocks in an embayment of Long Island Sound was made on five occasions over 2 years. Analyses of acid digests of the biomass collections for copper, chromium, zinc, nickel, lead, cadmium, mercury, and selenium showed no evidence of elevated levels in the colonizing biomass growing upon coal waste blocks, compared with that which was collected at the same time from concrete block controls (Roethel et al., 1980).

Suspension feeding organisms which filter particulates from large volumes of surrounding seawater would be especially vulnerable to releases of block components. Tests for trace element uptake were made by holding actively feeding blue mussels, *Mytilus edulis*, for 3 weeks in aquaria with different sediment loadings of finely powdered coal wastes, which were kept in suspension by slow agitation. The mussels were fed on phytoplankton and ingested the particulates with their food; particulates were subsequently found in their fecal pellets having passed through the gut. Microanalyses of digests of the soft tissues of experimental mussels for trace elements showed significant elevations of tissue iron concentrations, which are not toxic. But no increases were found in zinc, lead, nickel, manganese, or cadmium. As this study continues, more elements such as arsenic and mercury are being included. But on the basis of the initial results, it does not appear that filter feeders had accumulated toxic elements from the ingestion of coal waste particulates.

Figure 5.—Cunner and blackfish at Fire Island Reef.

Habitation by Fish

Divers reported that fishes had already begun to move into the nooks and cran-

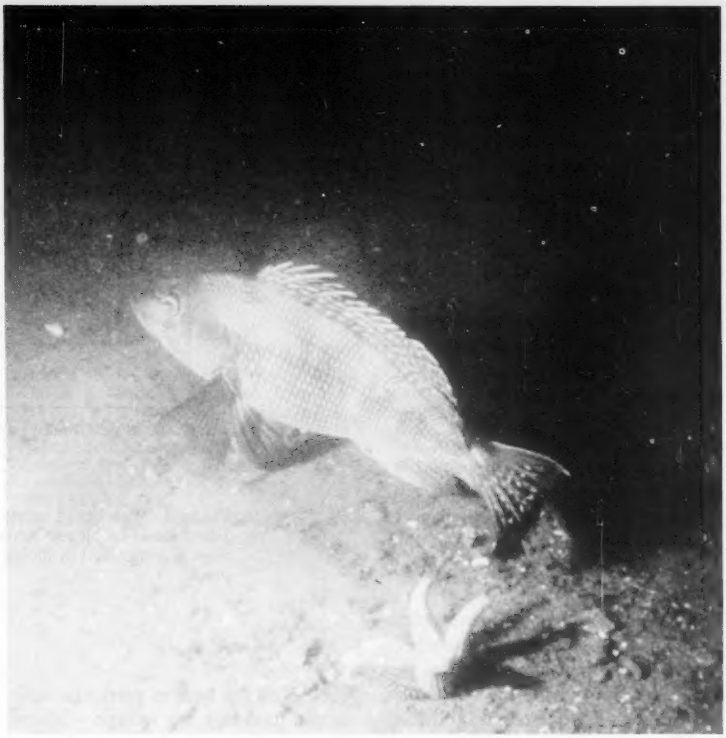

Figure 6.—Black sea bass occur in numbers from June to October.

nies of the new reef by the time of the first scuba survey, 5 weeks after placement on the seabed. Cunner, *Tautogolabrus adspersus*, were the initial inhabitants and remained the most numerous fishes throughout the first year of surveys. It was also the most abundant species on nearby Fire Island Reef (Fig. 5). Other species found at the reef during the first year's surveys were black sea bass, *Centropristis striata;* blackfish, *Tautoga onitis;* conger eel, *Conger oceanicus;* winter flounder; summer flounder, *Paralicthys dentatus;* ocean pout, *Macrozoarces americanus;* sea raven, *Hemitripterus americanus;* and longhorn sculpin, *Myoxocephalus octodecemspinosus* (Fig. 6). Adult rock crabs, *Cancer irroratus,* were early migrants to the reef and toward the end of the first year during summer, juvenile lobsters, *Homarus americanus,* 10-25 cm in total length, began to appear in increasing numbers.

A census of the fish populations taking up habitation on the new reef was made by regularly setting out fish traps in standard arrays, both on the new reef of waste blocks and also on an outlying section of the old Fire Island Reef nearby. The traps are rectangular, made from vinyl-coated 14 gauge wire and measure $90 \times 60 \times 30$ cm, and they have a single netting funnel about 60 cm long. The "soak" time is 2 days, two strings of traps being fished on the waste reef, with two additional strings fished on Fire Island Reef at the same time. (Fig. 7).

A storm wrecked much of the trapping gear the first time it was fished after placing the reef, but after replacement, the gear subsequently worked well, being

Figure 7.—Shooting a string of fish traps over the stern of SUNY research vessel *Onrust*.

fished throughout 1981. Average catches of fish showed increases from March through summer (Fig. 8), with cunner usually forming about 90 percent of the trap catch. Larger male fish were predominant among the early colonizers, but by summer small juveniles had recruited to the reef in numbers. Average catches on the Fire Island Reef were about twice as large but followed the same seasonal cycle of change and had a similar species composition.

The total area being fished at Fire Island Reef is not yet established but it is larger than the area of the new reef of blocks, which may account for the larger catches made. The catching efficiency of traps is influenced by temperature and the low catches made in spring 1981 (when temperature was low) in both situations probably do not reflect the density of fish on the reefs when compared with summer catches at higher temperatures.

Fish caught in the traps are in excellent condition and several hundred have been tagged with both plastic "spaghetti" tags and with Petersen buttons to provide information on the residence at the site by different species and on their seasonal movements. Perhaps more importantly, recaptures of tagged fish have been used to make first estimates of the size of fish populations at the reef.

Due to their abundance, the best available population estimate in the first year is for the cunner. Using all the recapture information from a sequence of tagged fish releases in 1981, two methods were used to calculate population size from the release-recapture experiments: Schnabel's method and modified Schnabel (Ricker, 1975). The two estimates of the numbers of adult cunner on the reef were 3,735 and 3,856 fish. The area of the waste reef is approximately 1,230 m^2 and the mean density of adult cunner on the reef in the first year was therefore about 3 fish per m^2. That density is already as high as Stone's (1978) estimates for adult cunner on rough bottoms in the New York Bight.

The reliability of these estimates will be reassessed in 1982. Population assessments will be extended to other fishes which have been tagged: Black sea bass, ocean pout, conger eel, and blackfish.

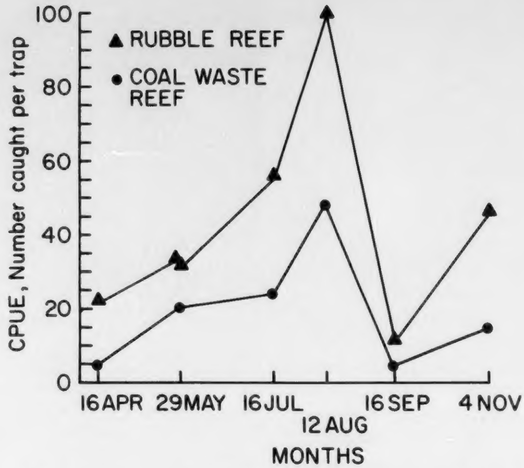

Figure 8.—Catches of cunner (cpue) at new reef and at Fire Island Reef ('rubble reef'). Note that low catches in September were accompanied by highly turbid conditions which reduce catch.

The black sea bass in particular have shown quite high tag returns — almost all coming from sport fishermen. Further growth and development of the epifaunal communities on the reef blocks are anticipated in 1982. We hope to determine the extent to which this occurs and whether epifaunal changes are matched by changes in the composition and size of fish populations inhabiting the new reef.

Conclusions

Since 1976, the C-WARP has made a wide variety of studies of the reactions of coal waste materials with seawater systems, both on small scale in the laboratory and, more significantly, at sites in the open sea. Our diverse data derived from these investigations of the physical, chemical, and biological interactions of different stabilized coal waste mixes in marine systems have so far all suggested that in the form of solid blocks, the material is compatible with the marine environment.

During some longer exposures, where blocks have been in the sea from 1 to 4 years, physical integrity has been maintained and material strength increased. Leaching of major components into seawater decreased exponentially with time and trace elements appeared to remain absorbed in the blocks. Different measures of biological acceptability have indicated that the stabilized material is not toxic to organisms in the sea. The study should continue for 3 years before assessments are made but already it appears that the cured blocks are suitable for biological colonization and overgrowth by epifauna, and that fish are resident in the reef.

Zawacki (1969) has made the point: "The use of waste materials . . . to construct artificial reefs may help solve some of the disposal problems of large cities while providing excellent fishing for the ever-increasing angling public." While agreeing, Jensen (1975) cited the need for caution and a systematic approach, to temper the zeal for building new reefs with due regard for regulatory requirements and accepted environmental safeguards.

The stabilization of coal waste into cured blocks for disposal may provide just such an example. If our extended program of testing and oceanographic monitoring continues to find the blocks

to be without adverse effects in the sea, an acceptable alternative may have been found to problems of disposal of coal combustion wastes from power plants. That solution would also carry benefits for the marine recreational fishing community through reef construction and marine habitat improvement.

Acknowledgments

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For the initial program, blocks of stabilized waste were donated for testing by IU Conversion Systems, Inc.; funding was provided by NYSERDA, the Link Foundation, and the New York Sea Grant Institute. We are very grateful to all of these agencies for sponsorship and to their program managers who provided advice and support at critical times in development of the project. Data for the sections concerning epibenthos, toxicity, and fishes were provided by Myrna E. Jacobson, Tim E. Cross, and Mark S. Alexander, respectively.

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Artificial Reefs as a Resource Management Option for Siting Coastal Power Stations in Southern California

ROBERT S. GROVE

Introduction

The Pendleton Artificial Reef was constructed in nearshore southern California waters (Fig. 1) in 1980. This artificial reef is a joint research project of the Southern California Edison Company (SCE) and the California Department of Fish and Game (CDFG) to assess the viability of man-made reefs as a compensation measure for the use of public resources in the form of cooling water for coastal power stations.

The CDFG, through a cooperative agreement with SCE, directed the design and construction of the Pendleton Artificial Reef and is conducting a resource management study on the reef. Specific reef management objectives are:

1) Determine whether a stable kelp bed can be established on a man-made reef in nearshore southern California waters;

2) Investigate the long-term stability and fisheries' (shellfish and finfish) standing crop on such a reef; and

3) Determine the appropriate size and design criteria of structural habitat modifications that will optimally enhance the selected fisheries' resources.

The concept of the Pendleton Artificial Reef project originated from specific marine studies associated with the operation of the San Onofre Nuclear Generating Station (SONGS) and general studies of coastal natural resources being conducted by SCE. This reef project was initiated to find a cost-effective, solution-oriented, marine resource enhancement scheme that would be applicable to SONGS and potentially any future coastal power plant.

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Background

An understanding of the history of the SONGS project and the evolving regulatory climate is necessary to appreciate the specific origins of the Pendleton Artificial Reef.

San Onofre Unit 1 began operation in 1968. Marine studies have been conducted in the San Onofre area since 1963. The San Onofre site is presently being expanded from a single 450 MW unit to 2,650 MW with two additional units and separate once-through cooling

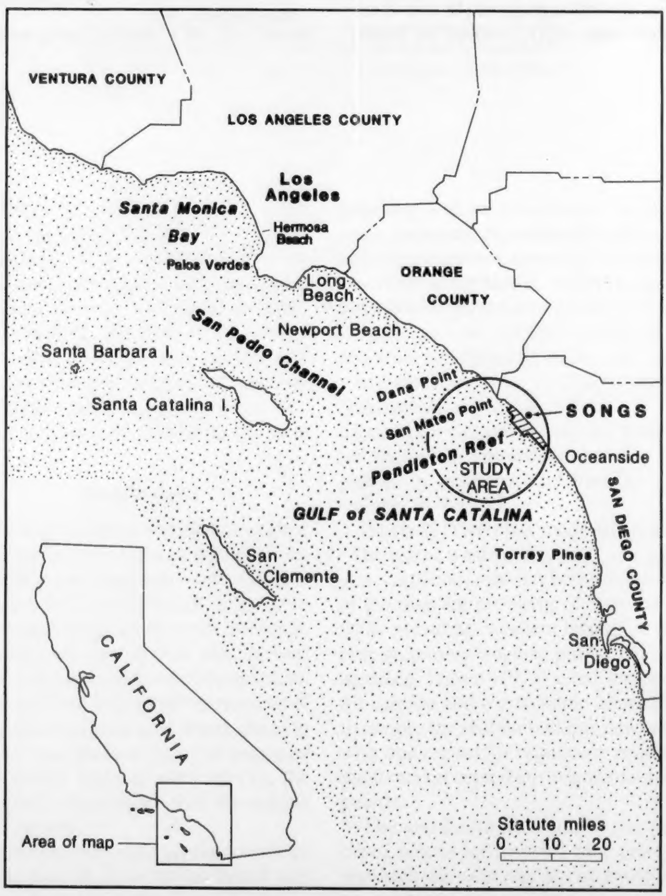

Figure 1.—Location of the San Onofre Nuclear Generating Station (SONGS) and the Pendleton Artificial Reef.

systems. The new units are due to begin operations in 1982 and 1983, respectively. Design and permit application work for Units 2 and 3 began in the late 1960's

By 1973 the environmental licensing process had progressed to the stage of obtaining a construction permit from the California Coastal Zone Conservation Commission (now the California Coastal Commission). In sequential order this was the 20th environmental protection-related permit in a series of 33 environmental permits connected with the licensing of Units 2 and 3 (SCE, 1976). The Coastal Commission approved a conditional permit which required the establishment of an independent scientific investigative group called the Marine Review Committee (MRC).

The MRC was charged to carry out "a comprehensive and continuing study of the marine environment offshore from San Onofre ... to predict, and later to measure the effects of San Onofre 2 & 3 on the marine environment ... in a manner that will result in the broadest possible consideration of the effects of Units 1, 2 & 3 on the entire marine environment in the vicinity of San Onofre" (Murdock, 1981). Further, the MRC must make recommendations to the Coastal Commission in the area of remedying any predicted adverse marine impact through cooling system design changes.

The MRC (1980) report to the Coastal Commission gave the predictions and recommendations of the MRC. It was recommended to not move the intake or discharge pipes or change the cooling system design, or to convert to cooling towers. The recommendation was to continue to monitor the marine environment and to initiate the examination of the feasibility of mitigating some or all of the predicted effects of the power plant on the environment. The option of recommending any actual power plant changes has been left open.

This has been a costly study: To date, SCE funding of these independent MRC studies has exceeded $17 million. The MRC is continuing its plankton, kelp, fish, and oceanographic studies with a 1981 budget of $3.29 million. As the MRC (1980) report to the Coastal Commission states: "Although we can and will obtain some more information on the major parts of the ecosystem near San Onofre Nuclear Generating Station before Units 2 & 3 begin operation, we have obtained most of the information it is possible to obtain with a feasible expenditure of effort. Where major uncertainties remain, further study will not, in general, resolve them. . . ."

It is this framework of events and costs that led SCE to develop the concept of compensatory resource enhancement through establishment of an artificial reef project. This represents a major departure from the standard practice of amassing an extensive marine data base which will most likely not succeed in resolving all present environmental uncertainties. Ultimately, reef management projects could at lease minimize investment in marine data collecting that cannot yield any possible significant return.

Pendleton Artificial Reef Planning

Active planning of an artificial reef began in 1979 at SCE. Initially, two possibilities for mitigating possible effects of coastal power plant circulating water systems were investigated for a site such as San Onofre:

1) The deployment of additional structures as part of, or adjacent to, a San Onofre-type cooling system to contain and utilize the waste heat output to enhance a general set of marine biotic resources at the site; and

2) The construction of structures away from the power plant site to enhance a specified set of marine biota resources of high social value that would compensate for "loss of like value" at the power plant.

The first alternative was suggested as a result of research being carried out by SCE on coastal power plants and possible marine habitat enhancement through specified design and operations modes of once-through cooling systems. For example, at SCE's Redondo Generating Station, the configuration of the King Harbor breakwater and adjacent power plant cooling system structures at the head of the Redondo Submarine Canyon, has led to enrichment of the fish fauna (Stephens, 1982). This biotic richness is apparently dependent on both the static and dynamic characteristics of the habitat created by the combination harbor/submarine canyon/cooling system configuration. Application to future power plant siting and cooling system design shows promise (Stephens and Palmer, 1979). Yet, whereas this option would provide the maximum direct association of the generating station with resource enhancement, the ability to manipulate the environment and biotic populations at an open ocean site such as San Onofre in a manner similar to the way it was done at King Harbor was not feasible as a demonstrative project because a new harbor or series of breakwaters would have to be built.

The second option, derived from past demonstrations in southern California, is that the productivity of a fishery can be enhanced by structural modification of the habitat, particularly in areas of low biological productivity. Artificial reefs have been employed successfully by the CDFG to enhance sport fisheries off the southern California coast (Turner et al., 1969). This option is viewed as most feasible and a straightforward trade-off: Where the influence of a generating station is viewed as negative, an equal or greater resource enhancement could be implemented in an adjacent location. The marine resources having greatest importance or value in terms of predicted losses due to the operation of coastal power plants are fish and kelp (MRC, 1980; Stephens, 1982). Both of these resources may be enhanced with artificial reefs as an offset to power plant impacts.

Pendleton Reef Preconstruction Activities

A site for the reef was chosen by SCE and the CDFG in proximity to San Onofre but away from any possible power plant influence, and in a relatively barren (with respect to fish and kelp), flat sandy bottom area. The reef location is approximately lat. 33°20′N, long. 117°31′W (Fig. 1). The CDFG made general reconnaissance surveys of the area and found it acceptable. Also, a control site for biological studies was concurrently selected nearby: Las Pulgas Reef (the inshore Barn Kelp Bed area), where

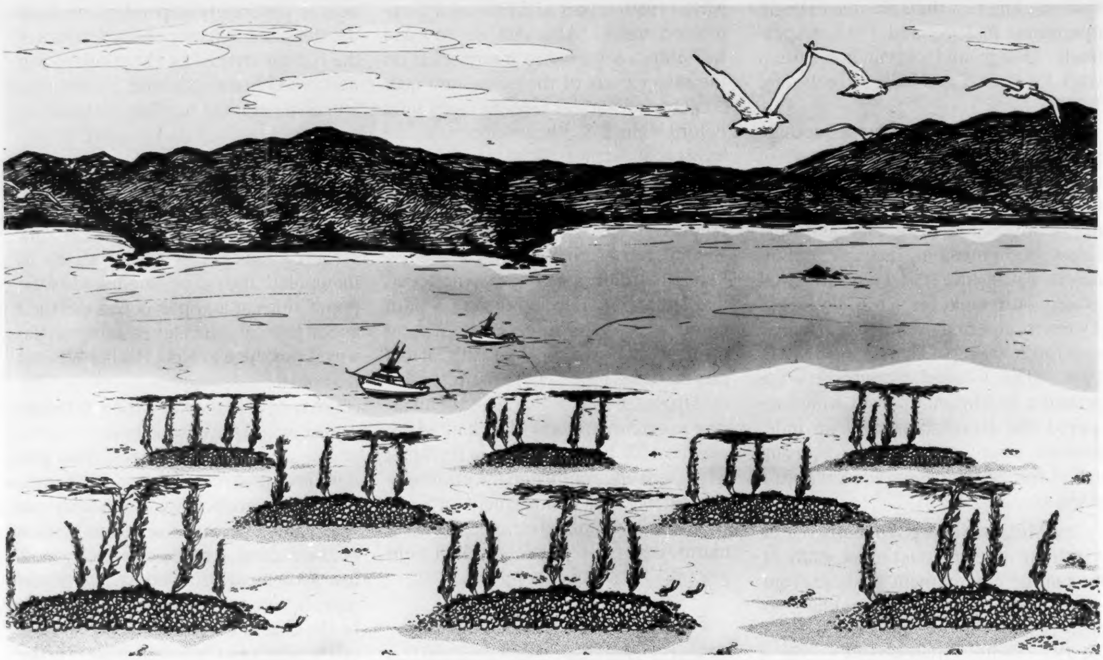

Figure 2.—Schematic of the Pendleton Artificial Reef.

substrate type and relief similar to the proposed artificial reef were found. Also, the Pendleton site, being adjacent to the marine biological and oceanographic surveillance zones of San Onofre, allows studies at the Pendleton Artificial Reef to draw upon 18 years of marine data for siting assessment and future comparative work. Another factor that was crucial in reef siting was proximity to natural kelp beds. The Pendleton Artificial Reef site is near natural kelp beds, both a few miles north and a few miles south, and the area has historically been recorded as a kelp area according to 1911 surveys.

The reef design and orientation took into consideration water currents and nutrient dynamics, criteria developed from previous CDFG reef building experiences, and comments received from expert reviewers from around the country. Reef configuration is shown in Figure 2. The reef was designed to incorporate basic ecological principles which should increase diversity and productivity. For example, the archipelagos arrangement was determined to be better than a single large mound, rugosity to be better than simplicity, relief was an important consideration, and heterogeneity over homogeneity was sought.

Reef Construction

Actual construction of the reef began in August 1980 and took less than 2 weeks. The reef was constructed of 10,000 tons of rock from the Connolly-Pacific[1] quarry on Santa Catalina Island. Total cost of the Connolly-Pacific operation, including barging and placement, was $250,000.

Eight reef units were constructed. Each unit measures about 100 feet by 40 feet with at least a 10-foot relief. The units are spread about 60 feet apart. All reef units are made up of rock mixture that has an approximate size range of 2-5 feet in cross section. Four reef units received a topping of relatively fine (1 foot cross section) quarry rock. The purpose of the "topping" is to provide shelter for small invertebrates and small fish[2,3].

Reef Management

Besides, the necessary reconnaissance of the area before reef placement, the CDFG, in its role of resource manage-

[1]Mention of trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

[2]Letter from Al Ebeling, University of California, Santa Barbara, to T. C. Sciarrotta, Southern California Edison. "Re: Review of March 3, 1980 Proposal on the Artificial Reef." 7 March 1980.

[3]Tegner, M., 1980. Scripps Oceanographic Institution, La Jolla, Calif., pers. commun. to B. Mechalas, South. Calif. Edison.

ment, performed surveys of the newly constructed reef, and is now involved in the manipulation of the reef with the purpose of maximizing resource yields for key fish and invertebrate species. For example, substrate is being altered to meet minimum design criteria established for life stages of certain taxa such as abalone. Also, kelp is being transplanted on the reef from surrounding areas to achieve a standing crop of parent *Macrocystis* plants. Natural kelp recruitment is an objective of this work. Kelp will increase the relief of the structure without making the reef a possible hazard to navigation, and fish seem to be attracted to higher vertical relief[4]. Kelp will also increase algal biomass sufficiently to allow a stable food web which includes invertebrates and fish.

SCE is providing 20,000 juvenile red abalone from its marine research laboratory at King Harbor to be transplanted on the Pendleton Reef (Kelly et al., 1982). The first transplant of 825 young abalone took place in July 1981. Follow-up observations through the summer of 1981 revealed that these abalone were showing new growth, and a transplant of 18,000 was performed in December 1981 (Fig. 3).

The CDFG is predicting that the reef will take about 6 years to reach a "natural" point of successional development, that is, to achieve an appearance similar to reefs of natural origin in the area. Even so, within weeks of reef construction sportsmen found the reef to be a desirable fishing point and commercial lobster fishermen now successfully set their pots on the reef. Through the rest of 1980 and the summer of 1981 the long-term ecological study program of the reef was being established. Reef physical parameters were measured and documented, and 5-year biological transects were set up. Observational dives and transplanting work were the main thrusts of the biological study activities during this time. The documentation of the reef's succession and further reef biomanipulation are the primary activities of the continuing CDFG work on the reef for the future.

[4]Sheehy, D. 1980. Artificial reefs as a means of marine mitigation and habitat improvement in Southern California. Report for the Marine Review Committee, 23 September 1980. Aquabio, Inc., Columbia, Md., 53 p.

Figure 3.—A CDFG biologist places juvenile abalone on the Pendleton Artificial Reef.

Conclusion

The Pendleton Artificial Reef project has demonstrated in its 1 year of existence that biological activity has followed an orderly succession to an apparently stable system that directly supports an enhanced fishery. The objectives of the Pendleton Artificial Reef and the continuing reef management study remain to establish a stable kelp bed on a manmade reef, to document the environmental stability and standing fisheries crop of the reef, and to determine the size and design criteria of structural habitat modifications that will selectively enhance desired marine resources in southern California. It is further hoped that this effort will lead to advances in artificial reef technology and marine resource management in coastal waters.

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Marine Habitat Enhancement and Urban Recreational Fishing in Washington

RAYMOND M. BUCKLEY

Introduction

In 1974 the Washington Department of Fisheries began a marine fish enhancement program designed to establish marine habitat enhancement (artificial reefs) and public fishing piers as accepted forms of fishery technology for improving urban recreational fishing in the Puget Sound region (Fig. 1). Both artificial reefs and fishing piers have been used extensively for many years in some of the Atlantic and Gulf Coast States and in California to improve recreational fishery catches and access in previously unproductive fishing locations (Steimle and Stone, 1973; Rickards, 1973; Fable and Saloman, 1974). In contrast, Washington's pier fishing facilities were limited to a few access areas on commerce docks, and earlier artificial reef efforts were small-scale projects designed to provide underwater recreation areas for scuba divers. None of these projects were primarily for shore fishing access or urban fishery enhancement.

Recreational fishing in Pacific Northwest marine waters has been synonymous with fishing for Pacific salmon (*Oncorhynchus* sp.) from small boats, and this axiom has pervaded from anglers, through fishery managers, to the funding sources. Consequently, a new program directed at enhancement of other marine fish species—using locally unproven techniques, and partially targeting these fish for an essentially unrecognized clientele—was met initially with feelings ranging from skepticism to enthusiasm. Fortunately, a significant amount of the enthusiasm to try habitat enhancement and public fishing piers was generated with the State government funding sources (i.e., the legislature and the Interagency Committee for Outdoor Recreation), the fishery clientele, and local government agencies and service organizations. This provided the broad base of public awareness and support which resulted in rapid funding of the initial projects.

During the first 7 years, the concepts of the marine fish enhancement program have been well received by the fishery clientele and have proven relevant to fishery management in Washington. Biologically, habitat enhancement structures placed in open, relatively unproductive marine locations successfully increase the areas' density and biomass of biota common to productive natural rocky reefs. Sociologically, public fishing piers have become extremely popular access locations for shore anglers previously denied use of the marine resources, and offshore "fishing reefs" near metropolitan areas have created valuable recreational benefits which are easily accessible to all boat anglers. Economically, habitat enhancement projects and public fishing piers compete very favorably with other forms of outdoor recreation for the public funds dedicated to recreational use.

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ABSTRACT—A marine fish enhancement program started in 1974 has emphasized the use of habitat enhancement structures (artificial reefs), both in conjunction with public fishing piers and to create "fishing reefs" for boat anglers, to improve urban recreational fishing in Puget Sound. The enhanced areas were designed and sited to develop biologically into replicates of natural rocky reef communities in order to promote productive fisheries.

The site selection process was based on indexes of the macrobiota assemblages on rocky reef control areas in the same region and on consideration of potential impacts on fisheries and commerce. Experimental design strategies for both the entire habitat enhancement area and the individual enhancement structures were used to determine the optimum balance between aggregation and production of target species and management for sustained, quality fisheries. Major structural design elements were found to be horizontal and vertical relief and numbers and sizes of interstitial spaces. Abundant and diverse algal growth on the enhancement structures increases habitat complexity and heterogeneity, and may well be the most important element in the transition from introduced materials to replicates of productive natural reefs. Successional development of fish communities appears to proceed from a principally aggregated species base during initial colonization to a "forager-aggregater" community structure as food items develop on the enhancement structures.

This progress justifies application of enhancement technology to "real" fishery management problems, in which solutions maximizing accessibility to all facets of the recreational fishery provided the greatest benefits to the public.

The objective of habitat enhancement, used either in conjunction with fishing piers or to create "fishing reefs" for boat anglers, was to establish enhanced areas that developed biologically into replicates of productive, natural rocky reef communities, with resilient populations of target species of fish which could withstand frequent fishing. The biological investigations related to habitat enhancement have been designed to understand and utilize the artificial reefs from the perspective that the only "artificial factor" in the reef is the original placement of the inert base material around and upon which the living, natural reef community evolves. An understanding of the factors influencing this development enables construction of habitat enhancement complexes compatible with environmental and biological constraints.

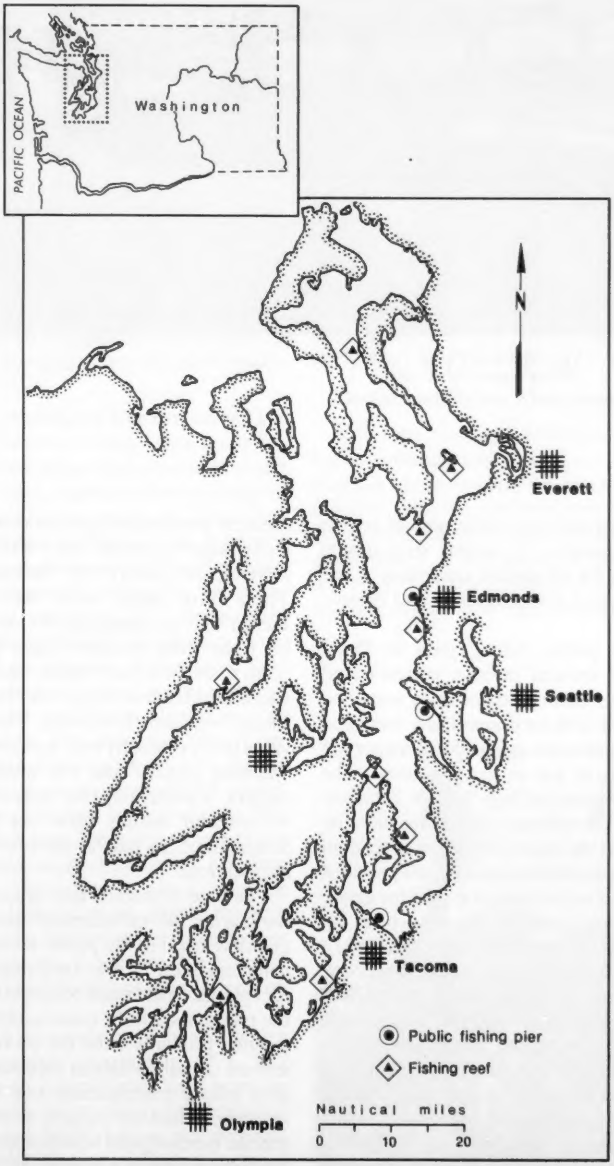

Figure 1.—Locations of habitat enhancement areas in Puget Sound, Wash.

Program Design and Methodology

The increasing demands for improvements in urban recreational fishing opportunities that were being recognized on a national level in the mid-1970's were also developing in the metropolitan areas of Puget Sound (PNRBC, 1970; BOR, 1977; Stroud, 1977). This emphasis on urban recreation offered the most potentially productive situations where applications of marine habitat enhancement would demonstrate the value of this technology in modern fishery management.

Many target fishing locations for rocky reef-oriented fishes adjacent to the metropolitan centers of Puget Sound began receiving more frequent use in the middle to late 1970's. This resulted from increasing interest in these previously less popular fishes, caused, in part, by curtailments in the fisheries for Pacific salmon dictated by the 1974 Boldt Decision (Williams and Neubrech, 1977) on treaty Indian fishing rights and, in part, by dramatic increases in energy (fuel) costs to reach more distant fishing grounds.

Many of these rocky reef sites were limited in area and habitat diversity and, therefore, supported vulnerable populations of the resident demersal fishes needed for a continuous fishery. Catches began decreasing in many of the more popular and accessible locations, and anglers either invested the additional

Figure 2.—The Edmonds Public Fishing Pier.

costs to travel to more productive locations, modified their criteria for productive catches, or withdrew from the fishery. Strong public sentiments developed for more productive urban fishing locations accessible (economically) to a broad spectrum of recreational anglers. The use of marine habitat enhancement to create productive nearshore fishing sites was an obvious and timely solution to this problem.

The introduction in 1975 of large public fishing piers (Fig. 2) to the urban recreational fishery scene in Washington presented an excellent "vehicle to gain visibility" for marine habitat enhancement in an essentially risk-free manner. Metropolitan areas in Puget Sound had the potential for developing a large pier fishing clientele, but there were no available facilities designed and sited specifically for recreational fishing. Most of the metropolitan centers bordered marine waters with good biological production potential and excellent fishing depths (from −27 to −55 m MLLW [mean lower low water]). This new urban fishery was virtually guaranteed to provide popular, accessible, and affordable participation in marine recreational fishing for all anglers, regardless of age or physical ability (Buckley and Walton, 1981).

The public fishing piers in Puget Sound created intense, concentrated fisheries that could not enjoy sustained catches without dramatically increased aggregation and production of important species of fish in the pier areas. The construction of large habitat enhancement complexes around the piers increased the areas' production of resident and semiresident species, and provided feeding and orientation sites for aggregation of transient species—both important in sustaining quality catches in a continuous fishery situation. This combination of fishing piers and habitat enhancement brought the concepts and benefits of habitat enhancement into contact with the maximum number of anglers in a "high profile" fishery at the start of the marine fish enhancement program.

Later use of habitat enhancement to create "fishing reefs" for the boat fishing clientele was the first application of this technology to benefit an established recreational fishery in Washington. These "boat angler reefs" were sited every 18-28 km along the 185 km cruising route from southern Puget Sound north to the San Juan Islands, and were also accessible from major recreational fishing boat launch facilities. This provided the opportunity both to occasional "yachting anglers" and avid small-boat anglers, representing the bulk of the recreational fishing effort on Puget Sound, to utilize habitat-enhanced fishing locations.

The base of interest and support for the marine fish enhancement program that developed in the public sector was complemented by the very important acceptance of the same concepts within the relevant scientific community. This resulted primarily from the promotion and use of marine habitat enhancement as a fishery management tool which secondarily had the capacity to recycle specific types of solid wastes under ecologically acceptable conditions. There is some evidence that earlier local (and

national) emphasis on relating artificial reef construction to deposition of a variety of solid waste materials in the marine environment resulted in waste disposal often being perceived and promoted as the primary justification for reef construction. A further consequence of this misconception was the trend that artificial reef projects had to be minimal budget operations supported by donations of materials and volunteer labor, which led to the traditional corollary that artificial reef projects did not require public funds and, therefore, had little intrinsic value. In contrast, the representation of marine habitat enhancement as a valid fishery management technique worthy of investment, the same as freshwater fish-producing facilities (and lacking anything synonymous with the term "artificial"), utilized this traditional view in a positive manner and supported the investment of public funds through the use of donated materials, when appropriate.

The Washington Department of Fisheries receives construction funds for marine fish enhancement projects as part of the State legislative biennial appropriations for the agency's Capital Outdoor Recreation Budget. The source of these appropriations is a 50 percent State Government/50 percent Federal Government matching fund administered through the State's Interagency Committee for Outdoor Recreation. The State's share of the fund is obtained from voter-approved Referendum Bonds for recreation. The Land and Water Conservation Fund, administered by the Heritage, Conservation, and Recreation Service (absorbed by the National Park Service in June 1981) of the Department of Interior, supplies the Federal matching funds. The implementation of these capital appropriations, and the research supporting the marine fish enhancement program, are funded by the biennial Operational Budget of the Marine Fish Program.

Since the inception of the marine fish enhancement program in 1974, \$3.2 million in capital funds have been appropriated for marine habitat enhancement and public fishing pier projects. The 1981-83 Capital Budget included \$2.5 million for 14 habitat enhancement projects, three associated with public fishing piers. An additional \$1.2 million is scheduled for appropriation for another fishing pier project in 1983. This funding base, which has established two public fishing piers and two "boat angler fishing reefs" and has one fishing pier and eight fishing reefs under construction, is only as stable as its two funding sources. Anticipated Federal reductions and delays in the Land and Water Conservation Fund appropriations to the states in 1982 will cause severely curtailed construction schedules, and have created interest in establishing a 50 percent Federal Government/50 percent local government matching fund approach for some projects. This release of State Government funds would enable 100 percent State funding of some projects, if current economic inflation factors do not prohibit continued sale of recreation bonds.

Site Selection, Facility Design, and Fishery Management

Successful biological development of habitat enhancement projects in marine waters is a key prerequisite to productive fisheries on the enhancement structures. To maximize the potential for biological development, a site-selection process was used which relied heavily on a biota indexing comparison system developed for the Puget Sound region (Hueckel and Buckley[1]). This system was based on indexes of the macrobiota assemblages on three natural rocky reef control areas which had stable, diverse communities of algae, invertebrates, and fishes, and were productive recreational fishery sites. Biota common to all three areas were assumed to typify those that would occur on habitat enhancement structures placed in areas with the environmental parameters conducive to productive biological development.

Transects conducted on potential habitat enhancement sites qualitatively assessed the biota in relation to prevailing substrate characteristics. Artifacts and substrate anomalies on the site (such as atypically large rocks, logs, and man-made debris, Fig. 3) were examined carefully. Their attached and related biota were representative of the biota that would develop on the site with the addition of stable material to increase the diversity and relief of the substrate. A high percent overlap between the control site and enhancement site biota was indicative of a good habitat enhancement site, although the opposite relationship was not necessarily true, espe-

[1]Hueckel, G. J., and R. M. Buckley. Site selection procedures for marine habitat enhancement in Puget Sound, Washington. In prep.

Figure 3.—Auto-tire artifact on sand substrate.

Figure 4.—Scrap concrete used for habitat enhancement construction.

cially if rocky reef simulating substrates were not available.

The site-selection process also considered several other factors relevant to ensuring that the habitat enhancement structures attracted desirable biota and fishery utilization, and not unwanted sediments or commercial fishery nets. Conflicts with existing and future fisheries were analyzed to avoid overlapping utilization of the area, if possible, or to determine the most beneficial use of the site. Conflicts with commercial vessel traffic were avoided, both in relation to vessel draft restrictions caused by the enhancement structures and to surface congestion caused by fishing boats. The proximity of the enhanced site to recreational access locations was also important to facilitate utilization and, therefore, maximum public benefits.

Various design strategies for both the entire habitat enhancement areas and the individual enhancement structures were used to determine the optimum balance between aggregation and production of target species and management for sustained, quality fisheries. These experimental design considerations required habitat enhancement construction techniques that went far beyond the "random dump and hope" methods used in earlier artificial reef projects, occasionally involving underwater construction and placement of enhancement structures by scuba divers.

The habitat enhancement complexes surrounding public fishing piers cover from 1.5 to 2.0 hectares, which are far larger areas than can be fished from the piers. This design strategy makes 20-30 percent of each pier's enhanced area accessible to pier angler's gear, and allows the bulk of the enhancement structures to build reserve populations of resident and semiresident fishes to replenish removals by the pier fishery. A companion management strategy reserves these populations for pier anglers by closing the enhancement areas to all other fisheries. The "extra large" enhanced areas and the associated biota also serve as attractive target feeding locations for transient (often pelagic) species of fish, holding them within reach of the pier fisheries for extended periods.

Individual habitat enhancement structures are located either under the pier or outside of a 23-30 m perimeter surrounding the pier. This creates an "open zone" around the pier to minimize gear fouling on the enhancement structures and makes both open sand-bottom and rocky reef fish species available to the pier fishery harvest. Conservative harvest management regulations are being tested to provide recreational enjoyment at reduced levels of impact on these, usually resident, target species.

The habitat enhancement complexes creating fishing reefs for boat anglers utilize up to 10 hectares of the bottom between the −13 to −27 m MLLW depths. These rather extensive areas allow a design strategy that distributes and spaces both the enhancement material and the ensuing fishing effort. Research has shown that large peripheral open feeding areas are important to some rocky reef fishes during specific life history stages (Hueckel and Stayton, 1982) and that aesthetic enjoyment in a recreational fishery can be increased by reducing crowding in the fishing area. An extensive enhanced area also enables management strategies that disperse or relocate fishing effort to reduce the impacts on fish populations inhabiting specific enhancement structures, such as spawning aggregations, juvenile recruitment areas, or overfished target locations. This can often be accomplished by utilizing the "magnetic buoy factor" which results in recreational anglers fishing only around the buoy that marks the fishing reef. Fishing effort can be evenly distributed by periodically moving the buoy to different locations throughout the enhanced area.

Theoretically, a fishing reef for boat anglers is totally accessible (if totally locatable), and it is not practical to offset fishery removals through building reserve populations of fish by closing a portion of the reef to fishing. The potential for overfishing is, therefore, much greater on a boat angler's fishing reef than in an enhanced area associated with a fishing pier, and this factor must be considered in the fishery management strategy. Conservative harvest management regulations are usually inappropriate in these situations, as they would have to apply to large geographic areas surrounding the fishing reef to be enforceable and would unnecessarily restrict other fisheries.

Experimentation with the design of the individual habitat structures is being examined as a method to control the rate of fishery removals over a long period of time, especially for the resident and semiresident species which utilize the structures for productive habitat. Enhancement structures constructed from large, angular material (such as long, flat concrete planks, Fig. 4) create large cave-like habitats which have a high refuge potential from anglers' gear. This reduces (or controls) the fishability of the enhancement complex through physically preventing frequent contact between fish and fishing gear, but still allows harvest of those fish on the periphery of the structures. This construction technique also appears to minimize gear fouling on the structures.

Figure 5.—Rockfish (*Sebastes* sp.) utilizing small habitats on an auto-tire module.

Habitat Design, Colonization, and Ecosystem Development

The design of the marine habitat enhancement program in Puget Sound is based on directing the biota development on, and in close association with, the habitat structures toward a multispecies and multilife-history stage community. This follows the premise that biota diversity will lead to productive, relatively stable communities of organisms which have the resiliency to respond to fishery removals throughout development. However, it is apparent from other research that this premise may be flawed. In discussing a general hypothesis of species diversity, Huston (1979) pointed out that diversity has been both positively and negatively correlated with productivity by many authors. Sale and Dybdahl (1975) found that communities of coral reef fishes are likely to demonstrate only weak stability and that the equation "diversity = stability" has questionable validity. A saving (or modifying) factor may be that most of this work relates to tropical patch-reef situations and may not be totally applicable to temperate rocky reefs. Sale and Dybdahl (1975) also pointed out that a fuller understanding of community structure (and responses?) will urgently require far greater information on the biology of the species involved.

The work carried out to date in Washington's marine habitat enhancement program has shown that the design and relative spacing of enhancement structures influence ecosystem development in the enhanced area, from initial placement of the structures throughout their long-term development. Major structural design elements are 1) horizontal and vertical relief and 2) numbers and sizes of interstitial spaces. The latter element directly affects the sizes of the more cryptic fishes that colonize the structures and may also influence the species of fish and the sizes of some invertebrates. The spacing and sizes of the habitat structures affect the amount of interface with the surrounding pelagic and benthic environments, which has, as yet, an incompletely understood effect on interstructure relationships. It has been demonstrated that maintaining open zones within the enhancement areas is beneficial to both reef species (Hueckel and Stayton, 1982) and nonreef species (Walton, 1979).

Current literature on reef colonization supports the view that determination of the actual factors controlling this process is a continuing question, especially in temperate regions (Fager, 1972; Talbot et al., 1979; Stephens and Zerba, 1981; and others). Brock et al. (1979) examined recolonization in coral reef communities and found that "the structure of reef fish communities may be the result of a mosaic of deterministic patterns and stochastic processes that occur during initial colonization and continue through time." This finding supports the general consensus in the literature that the various resource-partitioning, space-limited, predator-limited, lottery-hypothesis, resource-sharing viewpoints all have their own areas of credibility as mechanisms which influence colonization, diversity, and stability in reef fish communities. For example, Russell et al. (1974, in Brock et al., 1979) working on the Great Barrier Reef, noted that the physical structure of artificial reef habitats was relatively unimportant in determining early colonization community structure, and Nolan (1975, in Brock et al., 1979), working in the Marshall Islands, could not find any obvious correlation between artificial reef substrate complexity and fish species diversity. However, Walton (1979), working in the Pacific Northwest, found that the structural design and physical placement of artificial reef modules affected the density and biomass of associated fish populations.

The structure of temperate reef fish communities in Puget Sound may be heavily influenced by chance factors on the species level, as long as suitably sized habitats are available to meet the needs of the life history stages (sizes) of the species recruiting to the reef (somewhat deterministic biological patterns?). Rockfish (*Sebastes* sp.) colonization of the auto-tire module and rubble rock enhancement structures associated with the Edmonds Public Fishing Pier followed a definite pattern of association between fish size and habitat selection. Small interstitial spaces formed by rubble rock were utilized by small rockfish up to 15 cm in length, and tire modules (triads) with large cave-like openings and small crevices showed rockfish distributions based directly on habitat size (Fig. 5, 6). This same pattern was observed in the initial colonization of scrap concrete enhancement structures at Gedney Island by both juvenile and adult rockfish,

Figure 6.—Rockfish (*Sebastes* sp.) utilizing a large habitat on an auto-tire module.

Figure 7.—Juvenile rockfish (*Sebastes* sp.) utilizing a narrow protective habitat.

where (protective?) habitat selection was strongly size-related and the area appeared to be habitat-limited for juveniles (Fig. 7).

The suitability of the habitats formed by enhancement structures has also been observed to affect initial colonization by such diverse biota as 8 cm shrimp and 100 cm predatory fish. Protective habitat for the coon-striped shrimp, *Pandalus danae*, a major food item for many fishes, consisted of the smaller interstitial spaces and often included the same crevices used by juvenile rockfish which would later become shrimp predators. Spawning territories for lingcod, *Ophiodon elongatus*, were established at sites with the appropriate semiexposed crevice habitats suitable for retaining large egg masses (up to 0.5 m diameter), which solidify to the shape of the crevice to prevent dislodging when washed by tidal currents (Fig. 8).

Selection of construction materials and techniques which allow optimum vertical and horizontal distribution of a variety of interstitial spaces provides the best potential base for successful habitat enhancement in local marine waters. Equally important, however, are the long-term physical and chemical stability of the construction materials and the amount of photic-zone exposure of the enhancement structures, both of which influence algal community development. Scrap concrete, auto tires, and quarry rock are all acceptable substrate materials, offering firm, textured surfaces, although concrete is currently the most cost-effective, durable, and structurally desirable for local marine habitat enhancement.

Abundant and diverse algal growth on the enhancement structures significantly adds to habitat complexity and heterogeneity, allowing more species and more organisms to coexist in the enhanced areas. This may well be the most important element in the transition from introduced materials to productive natural reef replicates with stable communities. Sessile algae are major contributors to the physical structure of communities in the marine environment (Fager, 1972), and the microhabitats created by their holdfasts and upper structures are used extensively by a variety of invertebrates that are potential food organisms (Hueckel, 1980). The increased predator-prey interactions availed by the increased production of food items provide greater choices for energy transfer through the food web in

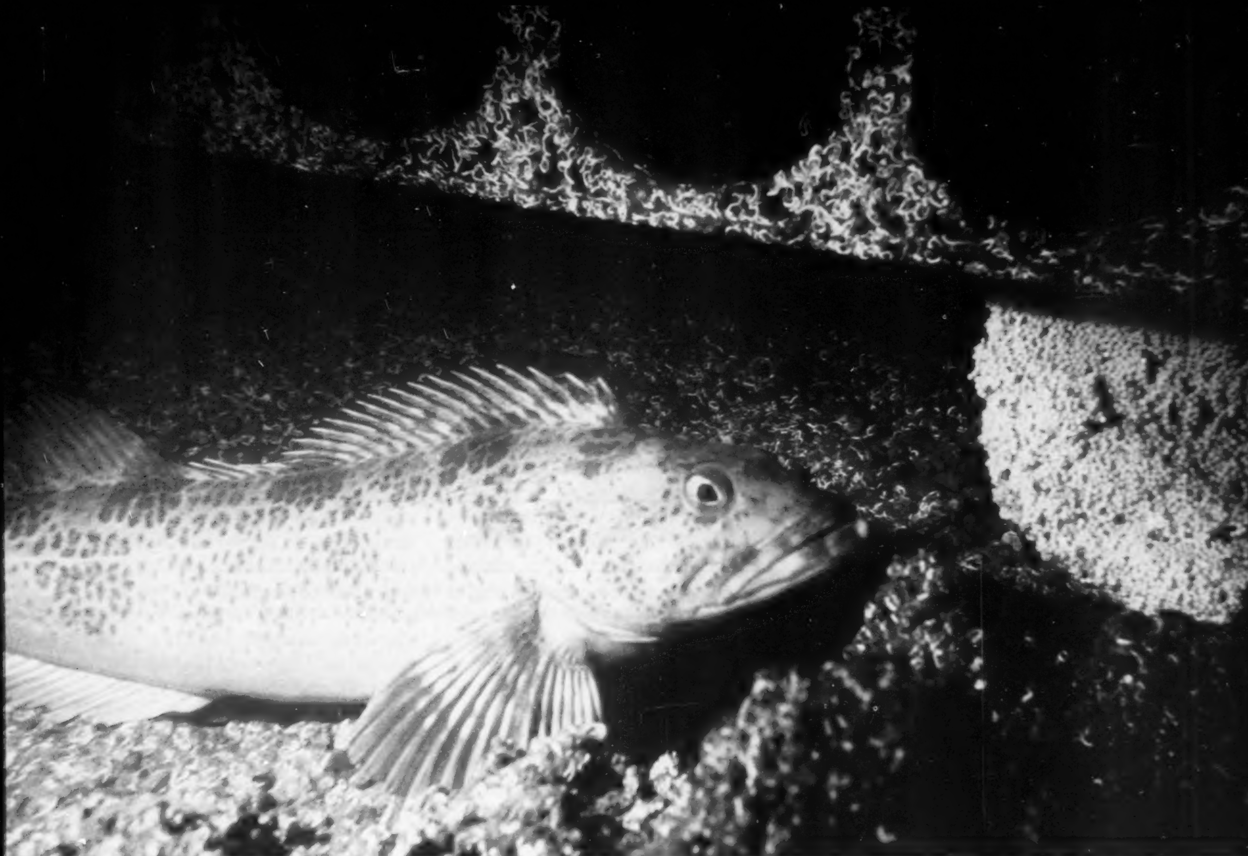

Figure 8.—Male lingcod, *O. elongatus*, guarding an egg mass.

the community, and the number of links in the food web is a measure of the stability of the community (Odum, 1953 in MacArthur, 1955).

The successional development of algae and invertebrates on substrates introduced into the marine environment has been well documented for many regions (Coe and Allen, 1937; Tsuda and Kami, 1973; Saito et al., 1976). Hueckel (1980) studied colonization of auto tire habitat enhancement structures at the Edmonds Public Fishing Pier for 24 months (1977-79) and found that algal development was very important to subsequent invertebrate colonization: "Prior to algal colonization, only [the crevice-related] coon-striped shrimp (*Pandalus danae*), two species of starfish (*Pycnipodia helianthoides* and *Evasterias troscheli*), acorn barnacles (*Balanus glandula*), and a sea anemone (*Metridium senile*) had been observed on the tires. After the development of algae on the tires, large numbers of gammarid amphipods, caprellid amphipods, harpacticoid copepods and hippolytid shrimp were observed associating with the algae .... *Platythamnion pectinatum* was the dominant red algae [Rhodophyceae] species on the artificial reef throughout the study. The filamentous structure and profuse branching of this species provided refuge for most of the microinvertebrates on the artificial reef." Walton (1979), studying the same enhancement structures, found that the species and numbers of fish increased with the age (increased development) of the habitats, the same pattern of development noted on nearshore artificial reefs in California and related to increasingly available food and shelter (Turner et al., 1969).

Acorn barnacles colonized the Edmonds enhancement structures in high numbers during the first spring, followed by rapid mortalities over a 4-month period, and never regained the initial high concentrations (Fig. 9). There is good evidence that this decrease was directly related to grazing by starfish (*P. helianthoides* and *E. troscheli*) and surfperch (*Embiotoca lateralis* and *Rhacochilus vacca*). Subsequent algal colonization occurred on the basal plates left after grazing and may have inhibited barnacle repopulation by preventing the larvae (cypris) from setting on the solid substrate. Red algae dominated the enhancement structures (approximately 95 percent coverage by *P. pectinatum*, and 5 percent by *Callophyllus* spp. and *Poly-*

neura latissima) and commenced to show the expected seasonal abundance cycle (Fig. 10).

This enriched habitat on the enhancement structures supplied microinvertebrate prey organisms (<2.5 cm in length) in concentrations up to 400/m^2, and macroinvertebrate prey organisms (including coon-striped shrimp) in concentrations up to 37/m^2 (Hueckel, 1980). Combined with additonal prey organisms occurring naturally in the surrounding sand substrate (Table 1), the entire enhanced area adjacent to the Edmonds Public Fishing Pier provided a productive feeding location for many species of fish (Hueckel and Stayton, 1982).

It is interesting to speculate (and possibly worth future consideration) whether ecosystem development on habitat enhancement structures could be controlled, or periodically altered, to increase the abundance and types of prey organisms. For example, would the introduction of large numbers of herbivores on some of the enhancement structures at Edmonds graze down the algae and allow recolonization by acorn barnacles? Could this be carried out immediately adjacent to the fishing pier to provide a prime feeding site for surfperch, which would be removed by the pier fishery before they could heavily impact the barnacle population, leaving an abundant food source to attract more surfperch (baited-trap equilibrium?)? Sale (1977) expressed the view that the diversity of coral reef fish communities was directly correlated with the rate of small-scale, unpredictable disturbances to the supply of living space, and that this could be tested experimentally by manipulating the rate of disturbance through increased predation (spear fishing). It seems equally plausible to experimentally control sessile and motile invertebrate populations on island-like enhancement structures.

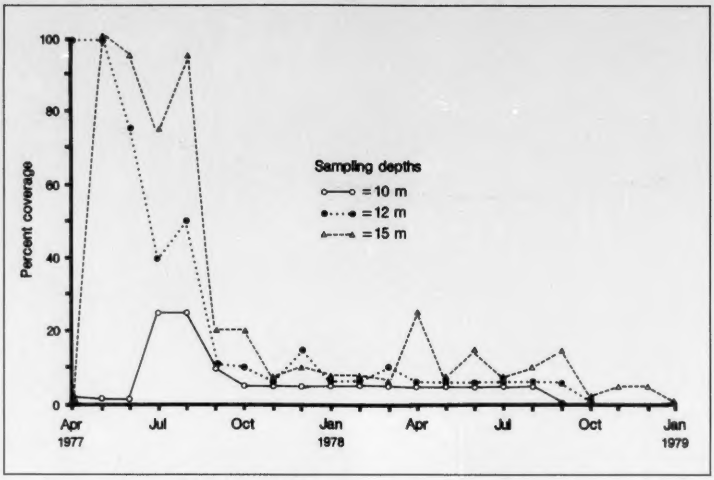

Figure 9.—Percent coverage of the acorn barnacle, *Balanus glandula*, on habitat enhancement structures at the Edmonds Public Fishing Pier (from Hueckel, 1980).

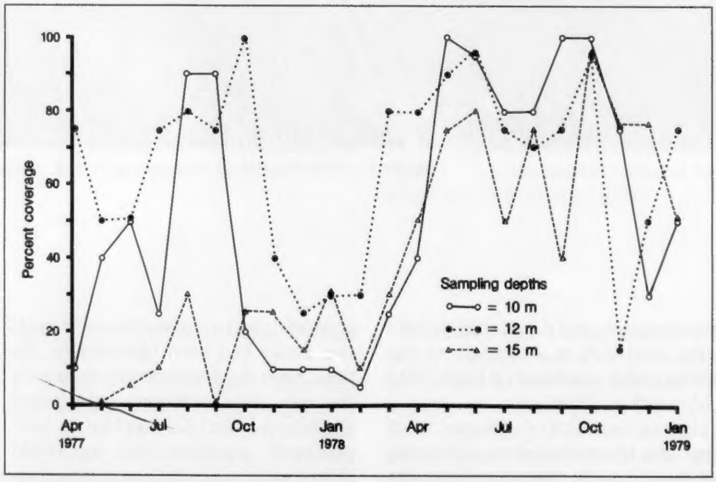

Figure 10.—Percent coverage of algae on habitat enhancement structures at the Edmonds Public Fishing Pier (from Hueckel, 1980).

Table 1.—Prey organisms identified in benthic cores, benthic plankton-net tows, and successional development studies in the habitat enhanced area at the Edmonds Public Fishing Pier, August 1977-December 1978.

	Percent	
Prey organisms	Habitat enhancement structures	Sand substrate
Microinvertebrates[1]	80	46
Caridean shrimp	20	
Polychaete annelids		33
Bivalve mollusks		15
Nematodes		6

[1]Less than 2.5 cm in length.

Long-Term Fish Community Structure

The successional development of fish communities on habitat enhancement areas in Puget Sound appears to proceed from a principally aggregated species base during initial colonization to a "forager-aggregater" community structure as food items develop on the enhancement structures. A composite of research information from several enhancement areas shows that the early colonizing fishes represent 1) five species of aggregaters, averaging 43 g each, which utilize the habitat structures for orientation and protection while feeding primarily on organisms from the surrounding benthic and pelagic environ-

Table 2.—Harvests of resident (R), semiresident (S-R), and transient-feeding (T-F) fishes from the Edmonds Public Fishing Pier.

Fishery year		Percent of harvest				
		First qtr.[1]	Second qtr.	Third qtr.	Fourth qtr.	Total
March 1979-	R + S-R	92.2	81.3	6.8	38.4	32.6
March 1980	T-F	7.8	18.7	93.2	61.6	67.4
May 1980-	R + S-R	83.5	22.5	49.6	65.8	40.1
May 1981	T-F	16.5	77.5	50.4	34.2	59.9

[1]Quarters overlap only 1.5 months between fishery years.

ments, and 2) two species of (predatory) foragers, averaging 1,553 g each, which utilize the habitat structures as a place to feed on structure-related organisms (principally aggregated fishes). After several years of biological development, the fish community structures change to represent five species of aggregaters, averaging 545 g each, and eight species of foragers, averaging 364 g each, with at least 60 percent species overlap in each group. These disparities in average sizes of early colonizing fishes demonstrate that the aggregaters were primarily juveniles (seeking unoccupied habitat?) and the foragers were (wandering?) adult predators. In comparison, the average sizes in the developed fish communities demonstrate a more balanced distribution of all aggregater and forager life history stages. This pattern of early colonization of reef structures by mainly juveniles, with some (itinerant) adult fishes, has been reported by many researchers (Talbot et al., 1979; Brock et al., 1979; and Stone et al., 1979).

Persistent aggregation of fishes by habitat enhancement structures is very important to continued fishery utilization of the sites. Foragers represent many of the resident and semiresident species that are limited in abundance by the amount of food and habitat (area) provided by the enhancement structures. The aggregaters include the transient species that utilize the enhanced areas as "patchy" feeding locations in rather broad geographic regions. These large populations occur intermittently in the target fishing locations, providing excellent catches and reducing pressure on resident and semiresident stocks, but are less vulnerable to overharvest. The first two fishery years on the Edmonds Public Fishing Pier produced harvests dominated by the transient-feeding fishes (67.4 and 59.9, respectively), but quarterly catch estimates demonstrated the equally important role of the resident and semiresident fishes in carrying the fishery through less productive periods (Table 2).

Stone et al. (1979) are the most recent researchers to show that marine habitat enhancement (an artificial reef) will increase carrying capacity and reef fish biomass in the immediate vicinity of a natural coral reef, without diminishing the resident population of the natural reef through attraction to the new habitat. Similar results have been found to occur in local temperate waters between new and old habitat enhancement structures which simulate rocky reef-like habitats. A quarry rock breakwater—rubble rock-covered pipeline habitat established in 1968-71, had fish densities averaging 0.27 fish/m^2 (quarterly, July 1975 to June 1976) just prior to construction of an adjacent tire-module artificial reef (Walton, 1979). Five years later, fish densities on this habitat had increased to 0.44 fish/m^2 while the tire modules had developed fish populations of 1.77 fish/m^2 (Washington Department of Fisheries survey data).

These examples of an absence of long-term detrimental effects between the new and old habitats, and the apparent relatively independent development of associated fish populations, support the idea that increasing the amount of reef-simulating habitat in the nearshore marine environment increases fish production. Local marine waters do not (currently) represent a nutrient-limited system that can be adversely affected by an expanding habitat enhancement program; in fact, there is a closer representation of a habitat-limited system that responds to increased habitat diversity with increased production of desirable biota.

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Fish Foraging on an Artificial Reef in Puget Sound, Washington

GREGORY J. HUECKEL and R. LEE STAYTON

Introduction

Fishermen and scientists have known for centuries that fish are attracted to solid objects. This knowledge has been used to increase harvests by creating artificial reefs on sand bottoms, thereby increasing the numbers of economically important fishes in the area.

Many factors are important to the success of an artificial reef in attracting fish, including the presence of food items (Breder and Nigrelli, 1938). Fager (1972) observed that organisms growing on experimental 1 m cubes off La Jolla, Calif., influenced the types of predators attracted to the cubes. Walton (1979) determined that new tire reefs in Puget Sound, Wash., attracted a higher percentage of surfperch (Embiotocidae) and rockfish (Scorpaenidae) than adjacent tire reefs 1 year older. He speculated that changes in the fish community are correlated with successional development of organisms growing on the artificial reefs.

This study was designed to determine the degree of foraging by two embiotocids (*Embiotoca lateralis* and *Rhacochilus vacca*) and one scorpaenid (*Sebastes maliger*) on organisms associated with an artificial reef in Puget Sound to increase our knowledge of the changes in the structure of the fish community during the reef's early stages of successional development.

Materials and Methods

The Study Area

The artificial reef is located off the west shoreline of Edmonds, Wash., 24 km north of Seattle (Fig. 1). It was built during the summer of 1976, and is composed of 88 tire modules constructed from 10,000 discarded tires (Walton, 1979). Five different configurations were spaced in groups on a flat sand bottom, occupying a total surface area of 1,450 m^2 in an 11-hectare area between 10 and 15 m below mean lower low water. The artificial reef lies 60 m offshore from a riprap breakwater and 200 m south of a ferry pier. Algal and invertebrate growth on the artificial reef began during the spring of 1977 (Hueckel, 1980). The surface of the tires forming the artificial reef was covered by a lush growth of algae in which a dense population of crabs, shrimp, amphipods, and harpacticoid copepods took refuge.

Field and Laboratory

All fish were collected for this study by spearfishing between August 1977 and December 1978. Collected fish were divided into three length classes (Table 1). Large numbers[1] of striped seaperch and quillback rockfish were observed in the study area and were speared exclusively from the artificial reef. Small pile perch also occurred around the artificial reef in large numbers, while medium and large pile perch were scarce[2]. Schools (footnote 1) of medium and large pile perch were subsequently observed near the riprap and ferry pier pilings. Pile perch from all length classes were speared from the artificial reef, riprap, and ferry pier pilings. All fish were

Table 1.—Length classes of fish collected from the study area off Edmonds, Wash., between August 1977 and December 1978.

	Length group (mm)		
Species	Small	Medium	Large
Striped seaperch	$\leq$120	121-250	$\geq$251
Pile perch	$\leq$120	121-250	$\geq$251
Quillback rockfish	$\leq$120	121-200	$\geq$201

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ABSTRACT— This study was designed to determine the degree of foraging by striped seaperch, Embiotoca lateralis; *pile perch* Rhacochilus vacca; *and quillback rockfish,* Sebastes maliger, *on organisms associated with an artificial reef in Puget Sound, Wash. Stomachs of these fish species, dissected from 609 fish speared on, around, and near the artificial reef between August 1977 and December 1978, were examined and the contents were compared with organisms present in the immediate area.*

Medium and large fish (over 121 mm for all three species) foraged more on organisms associated with the artificial reef than did small fish of the same species. Abundance of preferred food items of medium and large striped seaperch and quillback rockfish associated with the artificial reef was an important factor in attracting large numbers of these species. Conversely, medium and large pile perch were largely absent from the artificial reef due to a lack of preferred food items.

[1]Greater than 100 fish, either schooling or solitary, observed per dive.
[2]Less than 10 fish observed per dive.

speared during the mid-morning hours except in winter months. Striped seaperch and quillback rockfish were taken at night during winter since their abundance was highest during this time. No pile perch were collected during winter due to their absence from the study area.

In the laboratory collected fish were weighed, measured, and labeled. Stomachs were removed and preserved with 10 percent buffered Formalin[3]. Due to their extremely small size, we defined striped seaperch and pile perch "stomachs" as the anterior one-quarter of their digestive tract. Stomach contents were emptied into Petri dishes and examined under a dissecting microscope (10-30×). Individual prey items were identified, blotted dry, weighed to the nearest 0.001 g, and enumerated.

Prey items were ranked by the Index of Relative Importance (IRI) developed by Pinkas et al. (1971). This index was calculated as IRI = $FO(N+W)$, where FO is the percentage frequency of occurrence of each prey item, N is the numerical percentage of each prey item contributing to the total diet, and W is its percentage of weight. IRI values for prey items in fish from each length class were totaled, and were expressed as a percentage of the total IRI.

The substrate from which the fish were feeding was determined by matching prey items in the fish stomachs to their respective habitats. Habitats of prey were determined from benthic cores, plankton net tows through the algae covering the tire surfaces, and visual observations. Prey items were assigned to one of six different categories: 1) Artificial reef, 2) riprap and ferry pier pilings, 3) infauna (on and in sand), 4) epifauna (free moving, in reef algae and sand), 5) planktonic, and 6) unknown. Category 2 applies to only those prey items from pile perch speared around the riprap and ferry pier pilings.

To correlate feeding habits with prey habitat we assumed fish did not migrate from outside of the immediate area of capture during feeding. This assumption seems justified since 1) striped seaperch and pile perch were observed feeding in the same area over extended periods of time; 2) prey found in the anterior gut suggest recent ingestion; and 3) a lack of extensive migratory movements by quillback rockfish was shown by Walton (1979). However, a few stomachs from medium and large striped seaperch and pile perch from the artificial reef con-

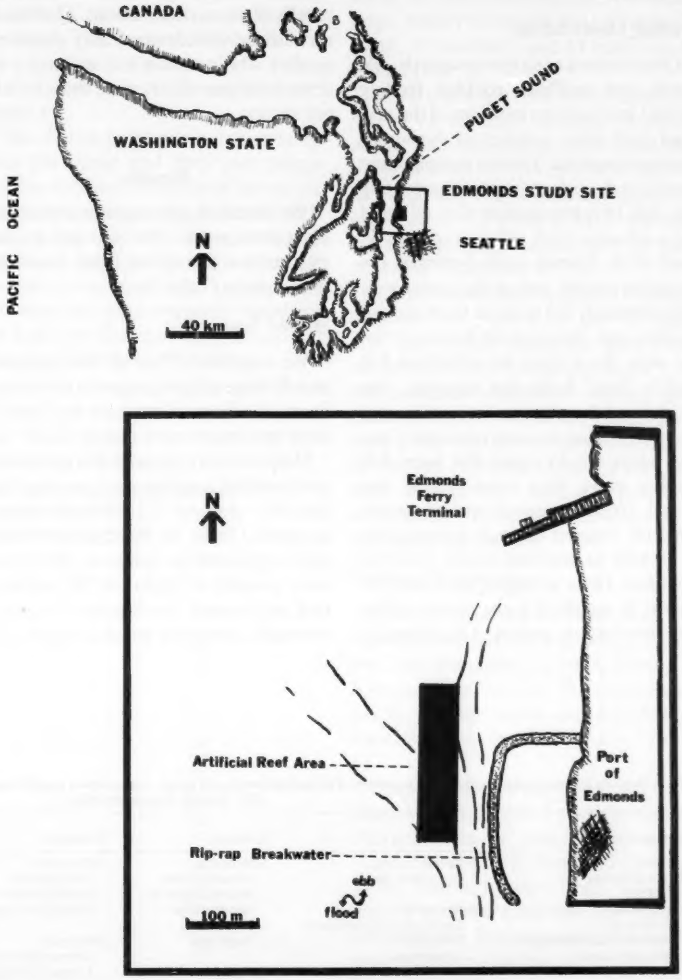

Figure 1.—Study area and location in Puget Sound.

[3]Reference to trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

tained trace amounts (<0.1 percent IRI) of contents foreign to the reef indicating they migrated from other areas after feeding. Infrequent occurrence of these foreign contents suggests migrations are uncommon.

Feeding Observations

Observations of striped seaperch, pile perch, and quillback rockfish feeding around selected tire modules of the artificial reef were conducted during 84 5-minute periods. Twenty stations were established, each station encompassing one side of a tire module (7.6 m^2), and the sand area (15.0 m^2) immediately in front of it. During each 5-minute observation period, one of the authors sat approximately 3.3 m away from the tire module and observed fish feeding from the area. Each time an individual fish took a "bite" from the substrate, the species and length class of the fish, and the type of substrate were recorded. Care was taken not to count the same fish feeding more than once during the period. Striped seaperch and pile perch generally foraged in small aggregations (< 10 fish) so that individuals could be identified. Once an aggregation left the station, it usually did not return within the observation period. Occasionally larger aggregations (> 10 fish) foraged from the stations, in which case there may have been some repetitive counts. However, this happened so infrequently that if there was any repetition, we feel it did not have any significant affect on the results of these observations. Quillback rockfish individuals were easily identified as they always remained sedentary in concentrations of not more than 10 fish per station.

Results

We identified prey organisms from 161 striped seaperch, 190 pile perch, and 194 quillback rockfish from seven different phyla (Table 2).

Striped Seaperch

We examined 27 small, 104 medium, and 49 large striped seaperch stomachs. Stomachs from 12 medium and from 7 large specimens were empty (Table 3).

Harpacticoid copepods and gammarid and caprellid amphipods dominated the diet (98.5 percent IRI) of small striped seaperch (Table 3). We classified these prey organisms as epifauna since they were present in algae on the artificial reef, and in sand. Small striped seaperch stomachs contained small amounts (1.0 percent IRI) of organisms which had been observed only on the artificial reef, primarily barnacles, *Balanus glandula.*

Medium striped seaperch foraged on epifauna (43.6 percent IRI), consisting primarily of gammarid amphipods and harpacticoid copepods; planktonic crustaceans (42.8 percent IRI), consisting entirely of brachyuran crab zoea obtained during the spring months; and brachyuran crabs (10.6 percent IRI) and *B. glandula* (1.3 percent IRI), from the artificial reef (Table 3).

Large striped seaperch fed from many habitats. Planktonic crustaceans (brachyuran crab zoea) comprised 38.0 percent IRI; epifauna (primarily gammarid and caprellid amphipods) accounted for 34.8 percent IRI. Organisms associated with the artificial reef structures (primarily caridean shrimp and brachyuran crabs) made up 13.8 percent IRI, while infauna (primarily polychaete annelids) accounted for 12.1 percent IRI (Table 3).

Pile Perch

We collected 71 small, 77 medium, and 52 large pile perch; 19 small, 42 medium, and 39 large pile perch were speared from the riprap and ferry pier pilings; and 52 small, 35 medium, and 13 large specimens were speared from

Table 2.—Habitats of organisms identified from stomachs of striped seaperch, pile perch, and quillback rockfish speared from the study area off Edmonds, Wash., from August 1977 through December 1978.

Artificial reef	Infauna	Epifauna	Planktonic	Riprap/ ferry pier pilings	Unknown
Arthropoda	Annelida	Arthropoda	Arthropoda	Annelida	Arthropoda
Balanus glandula	Polychaeta sp.	Harpacticoida	Calanoida sp.	Serpulidae	Crustacea sp.
Caridea sp.		*Acanthomysis* sp.	Euphausiacea		Mysidacea
Hippolytidae	Arthropoda	Gammaridea	Brachyura (zoea)	Arthropoda	
Eualus spp.	Ostracoda (Cypridinidae)	Caprellidea		*Balanus glandula*	Mollusca
Heptacarpus brevirostris	Cumacea	Paguridea	Vertebrata	Brachyrhyncha sp.	Gastropoda sp.
Pandalus danae	Tanaidacea		*Ammodytes hexapterus*	Oxyrhyncha sp.	
		Vertebrata	*Clupea harangus pallasii*	*Pugettia gracilis*	Vertebrata
Brachyura sp.	Mollusca	Cottidae			Teleostei sp.
Brachyrhyncha sp.	*Clinocardium nuttallii*			Mollusca	
Cancer oregonensis	*Pandora filosa*			*Mytilus edulis*	
Lophopanopeus bellus	*Transenella tantilla*			*Collisella pelta*	
Oxyrhyncha sp.	*Polinices lewisii*				
Pugettia gracilis					
Ectoprocta					
Membranipora sp.					
Mollusca					
Odostoma sp.					
Chlorophyta					
Ulva spp.					
Phaeophyta					
Laminaria saccharina					

the artificial reef. Empty stomachs occurred in one small, four medium, and five large pile perch (Table 4).

Small pile perch collected from the riprap, ferry pier pilings, and the artificial reef used the sand habitat for their primary source of food. Benthic crustaceans (ostracods and the clam *Transenella tantilla*) made up 93.3 percent IRI of the diet of small pile perch collected from the riprap and ferry pier piling habitats, and 87.3 percent IRI of the diet from small pile perch collected from the artificial reef (Table 4). Only 7.9 percent IRI of the diet of small pile perch collected from the artificial reef was obtained from the reef, and that consisted of the gastropod *Odostoma* sp.

Medium pile perch speared from the riprap and ferry pier pilings consumed clams, *T. tantilla,* and ostracods from the sand (68.1 percent IRI), and barnacles, *B. glandulà;* mussels, *Mytilus edulis;* and limpets, *Collisella pelta,* from the rocks and pilings (31.1 percent IRI) (Table 4). Medium pile perch captured from the artificial reef foraged basically on clams, *T. tantilla,* and ostracods from the sand (92.7 percent IRI) with only trace amounts (1.4 percent IRI) of their diet originating from the artificial reef (Table 4).

The diet of large pile perch speared from the riprap and ferry pier pilings habitats consisted primarily of barnacles, *B. glandula,* and mussels, *M. edulis* (95.0 percent IRI) (Table 4). Around the artificial reef, large pile perch fed less on encrusting organisms (60.4 percent IRI) and more on sand-oriented organisms (34.4 percent IRI) than they did around the riprap and ferry pier pilings.

Table 3.—Stomach contents identified from striped seaperch speared from the artificial reef off Edmonds, Wash., from August 1977 through December 1978.

	Percent Index of Relative Importance (IRI)[1]		
	Small	Medium	Large
	(*n* = 27; 0 empty)	(*n* = 104; 12 empty)	(*n* = 49; 7 empty)
Taxonomic Classification			
Annelida			
Polychaeta sp.		0.9	11.6
Serpulidae		0.8	0.4
Arthropoda			
Crustacea sp.			0.7
Harpacticoida	58.5	4.4	
Balanus glandula	0.8	1.3	0.4
Acanthomysis sp.			0.3
Tanaidacea	0.3		0.5
Gammaridea	35.3	39.0	28.1
Caprellidea	4.7	0.2	6.4
Hippolytidae			2.4
Eualus spp.			2.1
Heptacarpus brevirostris			0.4
Pandalus danae			1.4
Brachyura sp.		10.4	4.6
Brachyura (zoea)		42.8	38.0
Brachyrhyncha sp.		0.2	
Cancer oregonensis			0.7
Pugettia gracilis			1.3
Ectoprocta			
Membranipora sp.	0.2		
Chlorophyta			
Ulva spp.			0.5
Total	99.8	100.0	99.8
Habitat classification			
Artificial reef	1.0	11.9	13.8
Infauna	0.3	0.9	12.1
Epifauna	98.5	43.6	34.8
Planktonic		42.8	38.0
Unknown		0.8	1.1
Total	99.8	100.0	99.8

[1]Greater than 0.1 percent IRI.

Quillback Rockfish

We collected 229 quillback rockfish from the artificial reef between August 1977 and December 1978. Thirty were small, 99 were medium, and 100 were large. Empty stomachs were found in 2 small, 19 medium, and 14 large specimens (Table 5).

Small quillback rockfish foraged primarily on caridean shrimp, *Pandalus danae,* and brachyuran crabs from the artificial reef (51.8 percent IRI), as well as planktonic euphausids and calanoid copepods (34.1 percent IRI), and epibenthic gammarid amphipods (12.4 percent IRI) (Table 5).

Medium and large quillback rockfish obtained 95.0 percent IRI and 92.5 percent IRI of their respective diets from the artificial reef, foraging primarily on the caridean shrimp, *P. danae,* and crabs (Table 5). Planktonic brachyuran crab zoea contributed small amounts to medium and large quillback rockfish diets (4.6 percent and 4.7 percent, respectively), obtained exclusively during the spring months.

Feeding Observations

Feeding observations took place on four different days in September, October, and November of 1978. During 7 hours of observations, 353 striped seaperch, 197 pile perch, and 4 quillback rockfish were observed feeding (Table 6).

Striped seaperch and pile perch were observed to forage in a grazing manner characteristic of many embiotocids (Turner et al., 1969; Bray and Ebeling, 1975). Search for prey items was conducted with the head directed toward the substrate. Rapid pectoral fin movements stabilized the fish and feeding bites from the substrate were quick and distinct. At times fish were observed to feed interchangeably from tires and nearby sand. Feeding from the artificial reef was primarily from the algae covering the tire surfaces. Through examination of their stomach contents, fish were shown to be picking small invertebrates from algae shelters. On numerous occasions, striped seaperch were seen picking large pieces of algae from the substrate, followed by rapid mouth and opercular

movements resulting in ejection of the algae into the open water. This process was repeated several times by the same fish with the same piece of algae; this was probably a method of obtaining small invertebrates from the algae. It was not uncommon to find incidental pieces of algae in stomach samples of perch.

Medium and large striped seaperch fed more from the artificial reef than did small striped seaperch (Table 6). The majority of pile perch from all length groups were observed feeding from the sand (Table 6). Overall, the numbers of striped seaperch and pile perch observed feeding during the observational periods decreased with increasing size of the fish.

The small number of quillback rockfish observed feeding may be attributable to their preference for relatively large prey items. Feeding by quillback rockfish is probably confined to short intervals during the course of a day or night. One quillback rockfish was seen consuming a shiner perch, *Cymatogaster aggregata*, immediately above the artificial reef, while the remainder were seen eating the caridean shrimp, *P. danae*, on the artificial reef.

Discussion

Striped seaperch from all length groups foraged primarily on small, noncalcareous epibenthic crustaceans. Most prey items were present on the artificial reef and sand, making it impossible to determine the specific habitat from which these fish were feeding. Observations of striped seaperch revealed that medium and large fish fed predominately from the artificial reef, and that small striped seaperch fed equally from both habitats.

The optimal foraging theory states "... an optimal consumer should be willing to expend more energy [or time] to find and capture food items that return the most energy per unit of expenditure upon them" (Pianka, 1974). Assuming striped seaperch feed optimally, the net energy gained per unit of feeding time expended by medium and large striped seaperch is greater by feeding over the reef than by feeding over sand. This may be due, in part, to the larger size, or density, of

Table 4.—Stomach contents identified from pile perch speared from the artificial reef, riprap, and ferry pier pilings off Edmonds, Wash., from August 1977 through December 1978.

	Percent Index of Relative Importance (IRI)					
	Small		Medium		Large	
	Riprap/ ferry pier pilings (*n* = 19; 0 empty)	Artificial reef (*n* = 52; 1 empty)	Riprap/ ferry pier pilings (*n* = 42; 2 empty)	Artificial reef (*n* = 35; 2 empty)	Riprap/ ferry pier pilings (*n* = 39; 2 empty)	Artificial reef (*n* = 13; 3 empty)
Arthropoda						
Ostracoda (Cypridinidae)	65.1	32.4	26.9	22.1	0.2	3.4
Balanus glandula			11.7	0.2	75.3	56.4
Mysidacea						
Acanthomysis sp.						2.0
Cumacea					0.9	
Gammaridea	4.3	4.6		0.2		0.2
Hippolytidae				0.6		
Pandalus danae						2.8
Paguridae			0.3	5.1		3.0
Brachyura			1.0			
Brachyura (zoea)						
Brachyrhyncha			0.3			
Cancer oregonensis						
Oxyrhyncha			0.4			
Pugettia gracilis					0.4	1.2
Mollusca						
Gastropoda			0.4	0.3		
Collisella pelta	2.3		8.3		0.2	
Lirularia lirulatus				0.3		
Odostoma sp.		7.9		0.3		
Polinices lewisii						0.5
Clinocardium nuttalli				0.3		0.2
Mytilus edulis			9.4		19.7	
Pandora filosa						0.2
Pectinidae						0.7
Transenella tantilla	28.2	54.9	41.2	70.3	3.2	29.4
Total	99.9	99.8	99.9	99.7	99.9	100.0
Habitat classification						
Artificial reef	N/A	7.9	N/A	1.4	N/A	60.4
Riprap/ferry pier pilings	2.3	N/A	31.1	N/A	95.6	N/A
Infauna	93.3	87.3	68.1	92.7	4.3	34.4
Epifauna	4.3	4.6	0.3	5.3	–	5.2
Planktonic	–	–	–	–	–	–
Unknown	–	–	0.4	0.3	–	–
Total	99.9	99.8	99.9	99.7	99.9	100.0

[1]Greater than 0.1 percent IRI.

invertebrates that take refuge in the algae growing on the artificial reef in comparison with those found on open sand. Assuming small striped seaperch also feed in an optimal manner, there was no difference in the energy gained from the artificial reef or from the sand.

Throughout this study, striped seaperch were present in large numbers around the artificial reef. Walton (1979) observed that striped seaperch were absent from the study area prior to the placement of the artificial reef, even though Hueckel (1980) discovered that potential prey items were abundant on and in the sand. Walton (1979) also noted embiotocids were the first group of fish to colonize the artificial reef, even before algae and invertebrates started growing on the tire surfaces, and that the average size of early colonizing striped seaperch was smaller than striped seaperch on the older riprap and nearby sunken boat hulls, both of which were covered with invertebrates and algae. Observations made by the author on a bare, newly constructed concrete reef in Puget Sound show an overwhelming majority of 8,200 small to only 76 medium and large striped seaperch. Small striped seaperch appear to be attracted to artificial reefs for shelter or orientation; larger perch are subsequently attracted by the presence of organisms growing on the surface of the reefs.

Stomach contents from small pile perch captured from all habitats, as well as the in situ feeding observations, indicated a diet composed primarily of organisms living in or on sand. The artificial reef, riprap, and ferry pier pilings provided very small amounts of prey organisms for small pile perch, yet they were observed near all these structures in large numbers. Like small striped seaperch, small pile perch also colonized the artificial reef prior to the development of organisms on the surface of the tires (Walton, 1979), and were apparently attracted by the cover (or orientation points) offered by the artificial reef.

Few medium and large pile perch were observed around the artificial reef in contrast to many seen around the riprap and ferry pier pilings. Medium and large pile perch fed primarily on barnacles and mussels around the riprap and ferry pier

Table 5.—Stomach contents identified from quillback rockfish speared from the artificial reef off Edmonds, Wash., from August 1977 through December 1978.

	Percent Index of Relative Importance (IRI)[1]		
	Small	Medium	Large
	($n = 30$; 2 empty)	($n = 99$; 19 empty)	($n = 100$; 14 empty)
Taxonomic Classification			
Annelida			
Polychaeta sp.			
Arthropoda			
Crustacea sp.	0.3		
Calanoida	23.8		
Gammaridea	12.4	0.3	0.7
Euphausiacea	10.3		
Caridea sp.	8.5	4.0	1.4
Eualus spp.		2.6	
Pandalus danae	30.0	71.5	42.0
Brachyura sp.	12.2	15.3	46.7
Brachyura (zoea)		4.4	3.3
Brachyrhyncha sp.	0.5	1.0	0.3
Cancer oregonensis		0.6	1.7
Lophopanopeus bellus			0.2
Pugettia gracilis			0.2
Vertebrata			
Teleostei sp.	0.5		1.4
Ammodytes hexapterus		0.2	
Clupea harengus pallasi			1.4
Cottidae sp.			0.4
Phaeophyta			
Laminaria saccharina	0.6		
Total	99.3	99.9	99.7
Habitat classification			
Artificial reef	51.8	95.0	92.5
Infauna	0.2	—	—
Epifauna	12.4	0.3	1.1
Planktonic	34.1	4.6	4.7
Unknown	0.8	—	1.4
Total	99.3	99.9	99.7

[1]Greater than 0.1 percent IRI.

Table 6.—Numbers of striped seaperch, pile perch, and quillback rockfish feeding on the sand and artificial reef off Edmonds, Wash., during 7 h of observations.

	Striped seaperch						Pile perch						Quillback rockfish	
	Small		Medium		Large		Small		Medium		Large		Large	
Station	AR[1]	S[2]	AR	S	AR	S	AR	S	AR	S	AR	S	AR	S
1	10	8	5	4	3	3	3	3	1	0	0	0	0	0
2	6	7	1	0	1	0	1	2	0	0	0	0	0	0
3	12	43	2	0	2	0	1	17	0	0	0	0	0	0
4	14	7	7	6	2	1	5	0	4	5	2	2	0	0
5	6	5	3	0	3	0	0	0	1	4	0	0	0	0
6	2	3	2	0	3	0	1	3	0	0	0	0	0	0
7	7	4	3	0	3	2	3	4	3	0	0	0	0	0
8	4	0	4	5	0	0	3	4	0	3	0	3	0	0
9	6	0	3	0	2	0	1	1	0	1	0	0	2	0
10	2	0	8	0	0	0	1	9	0	0	0	0	0	0
11	3	11	0	0	1	2	2	4	0	0	0	0	0	0
12	12	8	5	3	1	0	3	13	2	3	0	0	0	0
13	6	1	1	0	2	0	1	1	0	0	0	0	0	0
14	1	1	4	0	0	0	0	9	0	0	0	0	0	0
15	0	5	3	2	0	1	1	13	1	0	0	0	0	0
16	3	5	1	3	0	2	1	7	0	2	1	0	1	0
17	9	2	0	0	0	0	1	1	1	0	1	0	1	0
18	2	3	2	0	2	0	0	3	0	5	0	0	0	0
19	2	2	1	1	3	0	1	2	0	7	0	0	0	0
20	3	8	1	0	0	1	4	13	0	1	0	2	0	0
Total	110	123	56	24	28	12	33	109	13	31	4	7	4	0
Percent	47.2	52.8	70.0	30.0	70.0	30.0	23.2	76.8	29.5	70.5	36.4	63.6	100.0	0.0

[1]Artificial Reef.
[2]Sand.

pilings; around the artificial reef feeding was proportionally more from sand. Barnacles and mussels heavily encrusted both riprap and ferry pier pilings. Initial barnacle population on the artificial reef was rapidly depleted to low numbers by starfish predation and mussels never colonized the tire surfaces. Subsequent algal growth on the tires inhibited barnacle repopulation. The small population of barnacles and failure of mussels to attach to the tire surfaces appear to have created a food shortage for medium and large pile perch on the artificial reef, suggesting these food organisms are an important attractant for these fish.

Quillback rockfish foraged more on artificial reef associated food organisms as their size increased. Medium and large quillback rockfish obtained nearly 100 percent (IRI) of their diet directly from the artificial reef. Walton (1979) observed that the average size of quillback rockfish increased over time on the artificial reef. Small quillback rockfish inhabited the artificial reef prior to algae and invertebrate colonization, indicating smaller quillback rockfish were initially attracted to the artificial reef for reasons other than food. The proximity of small quillback rockfish to small crevices in the artificial reef and their quickness to dart into these crevices when approached suggest they are benefiting from protection offered by the artificial reef. Subsequently, larger quillback rockfish were attracted to the artificial reef following the colonization by shrimp (Hueckel, 1980).

Summary

It was shown in this study the importance of organisms growing on an artificial reef to the diets of three Puget Sound fish species. Medium and large striped seaperch, pile perch, and quillback rockfish were attracted to the artificial reef more by the presence of food items than were the small fish of the same species. The small striped seaperch, pile perch, and quillback rockfish used the adjacent sand areas and plankton to forage for much of their diet, which emphasizes the importance of those habitats to these small fish. The numerous hiding spaces in the artificial reef were often used by the small striped seaperch, pile perch, and quillback rockfish as a refuge and must aid in protection from predation. The abundance of preferred food items on the artificial reef for medium and large striped seaperch and quillback rockfish was an important factor in attracting large numbers of these fish species. Conversely, medium and large pile perch were largely absent from the artificial reef due to a lack of preferred food items.

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The Effects of an Artificial Reef on Resident Flatfish Populations

JAMES M. WALTON

Introduction

The placement of artificial reefs in areas where historically only flounder populations were prevalent has been a common practice among those determining reef placement sites. This decision, based on the now accepted premise that addition of higher relief substrates increases the diversity, quantity, and biomass of fish species, assumes that these species are more desirable than the resident flatfishes. However, concern has been expressed by researchers and users about the effects these reefs have on the resident population. This question was aptly posed to researchers by Hoese (1978): "While it is clear that surface area is increased, addition of a hard substrate where a soft one prevailed, may discriminate against species preferring the soft bottom. As a flounder fisherman perhaps I do not want stocks of black sea bass, tautog and cunner increased if it interferes with flounder production. Does that happen?"

At the time this question was posed, a study was already being conducted in the Pacific Northwest to determine what effects artificial reefs have on resident species. To do so and ensure proper controls, it was first necessary to determine certain population characteristics (i.e. species, density, biomass, and size of the local flatfishes (Pleuronectidae and Bothidae)), construct an artificial reef, then continue the monitoring program to study the changes that resulted.

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This was accomplished between May of 1975 and March of 1979 as a portion of the Puget Sound Artificial Reef Study (Walton, 1979) and the marine habitat enhancement program of the Washington Department of Fisheries Marine Fish Enhancement Unit.

Materials and Methods

The study site is located at lat. 47°48′N and long. 122°23′W on central Puget Sound approximately 24 km north of Seattle, Wash. (Fig. 1). The flat compacted sand surveyed in the study area from a depth of 6 to 18 m below mean lower low water (MLLW), approximately 200 m from shore, is typical of much of the nearshore area in central Puget Sound. Although tidal fluctuations average 3.4 m daily, the maximum current at the study site rarely exceeds 0.9 km/hour. This minimal current and closeness to shore allows effective scuba sampling at essentially any time.

The flatfish population on the open sand was surveyed monthly beginning in May 1975 and ending in June the following year. Sampling was conducted using a flounder sampler (Fig. 2) (Walton and Bartoo, 1976). During the sampling dives, the diver proceeded to the maximum depth to be sampled and placed the stake at that depth. The flounder sampler was pushed through the sand along the desired depth contour, dislodging flatfish in a 30 × 2 m swath. The diver recorded each species, then estimated its length by comparing the length of the fish with the 10 cm spacing of washers on the head of the sampler. After a transect was completed, the diver rewound the reel to the stake and made

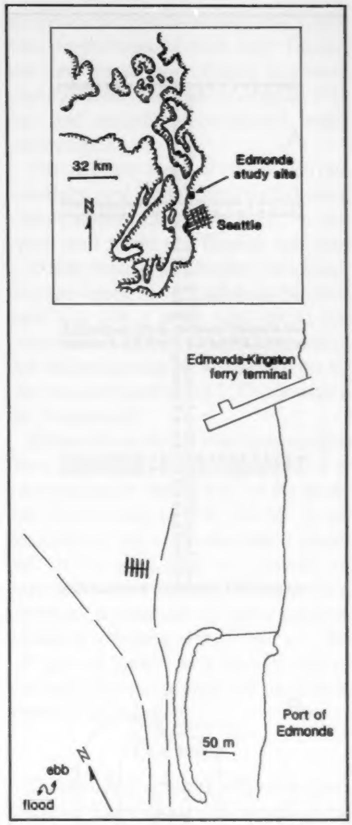

Figure 1.—Study site on central Puget Sound.

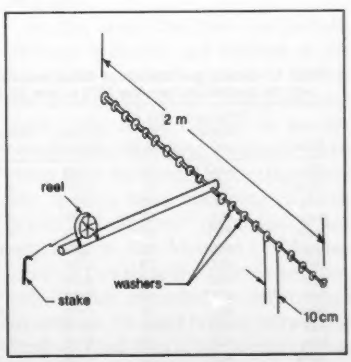

Figure 2.—Flounder sampler used to determine flatfish densities.

another transect run in the opposite direction. The monthly transects were run at 18.2 m, 15.2 m, 12.2 m, 9.1 m, and 6.1 m depths below MLLW. The weight of each individual was calculated from length-weight regressions determined for each species (Walton, 1979).

After completion of this survey an artificial reef was designed and constructed for the flatfish study. This reef design was termed the "horseshoes." The horseshoes (Fig. 3) were composed of rows of daisy patterns (a group of 8-10 tires secured at the tread by a short piece of line). Each of the three sides of a horseshoe was 7.62 m enclosing 58.1 m^2. The entire structure measured 30.5 × 15.2 m and encompassed a bottom area of 465 m^2. The total bottom surface area actually covered by tires was 228 m^2. The horseshoes were placed 12-15 m below MLLW.

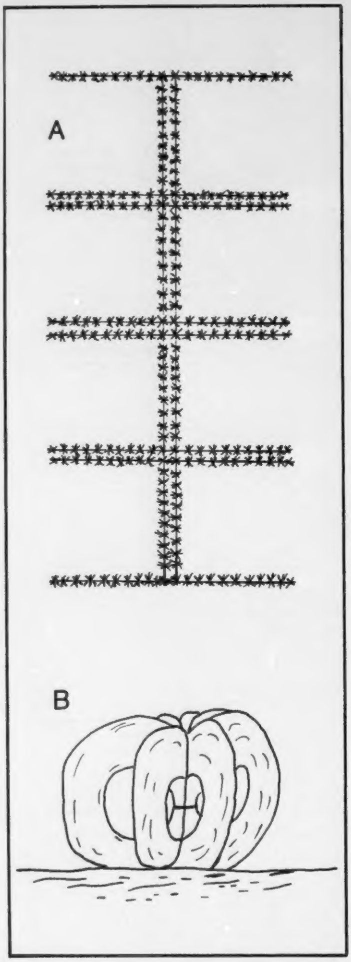

Figure 3.—The horseshoe tire reef configuration (A) is composed of individual bundles of tires (B). The individual bundles and the entire structure are held together with polypropylene line.

The horseshoes were sampled using flounder sampler transects inside the horseshoe openings. An area of 15.2 m^2 was surveyed inside each randomly selected horseshoe by swimming the 2 m wide transect from a line between the ends of the two legs to the back of the structure. Species were recorded as in the original sand bottom survey. Sampling commenced in October 1976, continued on a monthly basis through December of 1977, and then was conducted quarterly through March 1979.

Results

From May 1975 to June 1976, 427 fish were observed (Table 1, 2) of which 36 percent were rock sole, *Lepidopsetta bilineata;* 16 percent English sole, *Parophrys vetulus;* 16 percent C-O sole, *Pleuronichthys coenosus;* 15 percent sanddabs, *Citharichthys sordidus* and *C. stigmaeus;* and 17 percent unidentified flatfish. The two sanddab species in many instances were found to be indistinguishable underwater when less than 15 cm long and therefore were recorded only as *Citharichthys* sp. No significant difference in densities or biomass were detected between the 3 m depth intervals over the period studied (Friedman's 2-way analysis, $P = 0.20$); therefore, the data were pooled for further analyses. The average density for 1 year (January through December) summarized over the survey period was 0.07 flatfish/m^2 and the average biomass was 6.9 g/m^2.

Density and biomass would be expected to vary if the same size distribu-

Table 1.—Density and biomass of flatfish associated with the sand bottom from May 1975 to June 1976.

Month	Area surveyed (m^2)	No. of fish observed	Density (fish/m^2)	Biomass (g/m^2)
May	400	22	0.06	10.7
June	300	21	0.07	4.1
July	300	22	0.07	5.0
Aug.	600	56	0.09	6.2
Sept.	600	62	0.10	8.5
Oct.	600	73	0.12	10.6
Dec.	600	29	0.05	2.3
Jan.	600	16	0.03	5.2
Feb.	600	18	0.03	2.9
Mar.	600	18	0.03	5.8
Apr.	600	29	0.05	10.0
May	600	29	0.05	11.5
June	600	32	0.05	7.3
Average			0.07	6.9

Table 2.—Descriptive statistics of the species of flatfish on the open sand and within the horseshoe tire reefs.

Species	Habitat	Percent occurrence ($n = 12$ open sand) ($n = 19$ horseshoes)	No. of fish observed	Percent of no. observed	Average length (mm)	Average weight (g)
Rock sole	Open sand	100	152	36	209	106
	Horseshoes	100	210	40	198	90
English sole	Open sand	77	69	16	206	77
	Horseshoes	74	116	22	207	78
C-O sole	Open sand	92	68	16	298	356
	Horseshoes	100	39	7	307	389
Sanddabs	Open sand	92	66	15	145	32
	Horseshoes	68	43	8	143	31
Unidentified	Open sand	77	72	17	99	10
flatfish	Horseshoes	79	114	22	76	5
Sand sole	Open sand	0	0	0	0	0
	Horseshoes	5	1	1	300	300
Total	Open sand		427			
	Horseshoes		523			

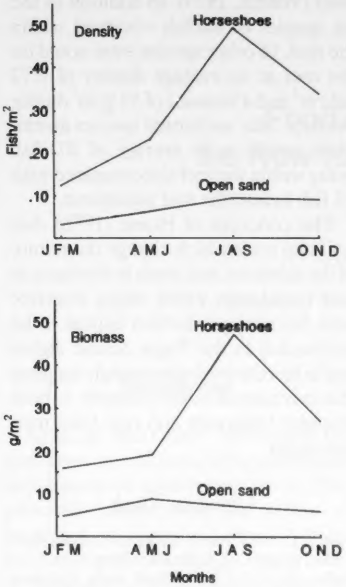

Figure 4.—A comparison of the density and biomass of flatfish observed on the open sand and within the horseshoe tire reef. Data points gathered over the entire study period are averaged by quarter.

Table 3.—The density and biomass of flatfish within the horseshoe structure from October 1976 to March 1979.

Year and month	Area (m^2)	No. of fish observed	Density (fish/m^2)	Biomass (g/m^2)
1976				
Oct.	84	32	0.38	31.7
Nov.	76	25	0.33	23.4
Dec.	76	13	0.17	26.9
1977				
Jan.	91	11	0.12	4.9
Feb.	76	6	0.08	16.0
Mar.	61	6	0.10	27.7
Apr.	61	7	0.11	11.1
May	76	18	0.24	33.8
July	122	72	0.59	56.2
Aug.	122	56	0.46	36.8
Sept.	91	38	0.42	54.6
Oct.	122	38	0.31	30.3
Nov.	122	43	0.35	18.4
Dec.	122	8	0.06	4.2
1978				
Feb.	122	7	0.07	3.5
May	76	35	0.46	37.9
Aug.	76	33	0.43	25.4
Nov.	61	61	1.00	58.5
1979				
Mar.	61	14	0.23	21.4
Average			0.31	27.5

tion of fish existed throughout the year. However, a few relatively large flatfish were encountered in the first quarter of the year increasing in numbers through the second. These were joined by large numbers of juveniles in the third quarter which remained through the end of the year before moving out of the study area. All of the flatfish species occurred in at least 77 percent of the sample dives. The unidentified flatfish group (UIF) averaged 10 g or about 5-10 cm. These small individuals were assumed to be juveniles of the other species, based on an otter trawl survey through the area.

For the period of October 1976 to March 1979 after the horseshoe shaped artificial reef had been constructed only one additional species, the sand sole, *Psettichthys melanosticus*, was observed. Rock sole composed 40 percent of the 523 fish recorded, English sole 22 percent, C-O sole 7 percent, sanddabs 8 percent, unidentified flatfish 22 percent, and sand sole less than 1 percent. The average density and biomass for the January to December cycle was 0.31 fish/m^2 and 27.5 g/m^2 (Table 3). Within the horseshoes, large fish were again encountered at relatively low densities in the first quarter. Juveniles, however, began appearing in the second quarter almost doubling the average density but only slightly increasing the biomass. The juveniles again remained through the third and fourth quarter.

A plot of the two sets of data for density and biomass calculations averaged by quarter appears as Figure 4. For the year and during each quarter the density and biomass of flatfishes are significantly higher within the horseshoes than on the open sand ($P \leq 0.05$) (Wilcoxon, 1945). The density of flatfish within the horseshoes was an average of 5 times that on the open sand while the biomass was 4.1 times greater inside the horseshoes.

Each of the species occurring on the open sand also occurred within the horseshoes. The sand sole was the only fish which did not occur in the initial survey. There was little difference in the percent of the samples in which each species occurred except for the sanddabs which were present in 92 percent of the samples on the open sand but in the horseshoe samples were only 68 percent. The proportions of rock sole, English sole, and unidentified flatfish increased slightly within the horseshoes while C-O sole and sanddabs constituted lesser percentages.

The average sizes of the rock sole, sanddabs, and unidentified flatfish were slightly smaller than those found on the open sand while the English sole and C-O sole were slightly larger. The overall average weight of the flatfish on the open sand was 106 g while that within the horseshoes was 79 g. Over 90 percent of this difference can be accounted for by the reduced numbers of C-O sole within the horseshoes.

Before the artificial reef construction there would be, on the average, 33 fish encountered in the 465 m^2 of the study site at a density of 0.07 fish/m^2. Construction of the reef eliminated about half of the area (228 m^2) leaving an exposed bottom area of 237 m^2 with a resultant population of approximately 73 fish at a density of 0.31 fish/m^2. The net gain in flatfish as a direct result of the reef was approximately 40 flatfish or a gain of 0.24 fish/m^2.

Discussion

Do artificial reefs affect flounder production? The evidence gathered during this study indicates that they do. Even though a certain number of fish are physically displaced by the construction of an artificial reef and the covered habitat is no longer accessible to them, the net result is an increase in flatfish abundance within the confines of the reef area.

In this study the four- to fivefold increase in density and biomass of the five most prevalent species of flatfish was the most significant change encountered. Only minor changes in species composition size and percent occurrence were detected. The fact that these five species were encountered both before and after reef placement is not surprising in that Moulton (1974) also reported that these five species were the only flatfish recorded in otter trawl samples on the sand bottom between a depth of 3 and 18 m at two similar central Puget Sound sites.

However, the placement of a reef on a

previously open sand bottom is a major perturbation at the site, undoubtedly resulting in small-scale current changes and changes in settling out patterns of detritus and debris, and it would seem likely that one or more of the species or a size range of one of the species would be better adapted to take advantage of these changes rather than all increasing about equally. As this was not the case several explanations might be postulated.

With changes in currents perhaps a greater settling out of algae, detritus, and plankton would occur on the bottom, being trapped by the legs of the horseshoes. This algae harbors many crustaceans (Hueckel, 1980) while the detritus and plankton contribute to clam and polychaete worm production. Flatfish commonly feed on small crustaceans, clam necks, and polychaete worms. Although no definitive studies have been completed comparing the food preferences of these flatfish at this site, generalized summaries of their preferences (Hart, 1973) suggest that there is a considerable overlap in their diets. This being the case, then an increase in food alone might account for the majority of the increase in flatfish abundance.

Other possible fish attractants include orientation and shelter (McVey, 1971). In this case the fish might simply be using the structures to hide behind, staying out of the direct line of sight of such roving predators as the lingcod, *Ophiodon elongatus*, then moving out to the nearby open areas to feed. This explanation is further supported by the fact that the changes in density occurred immediately after reef placement. In actuality all three factors are probably working simultaneously.

It should be noted that the artificial reef modules constructed for this study were designed with the idea that a semienclosed structure might increase the densities of flatfish species and that if so, other reefs, even though constructed of other components or materials, might be arranged so as to maximize flatfish species while also attracting other species. In a subsequent limited study the Washington Department of Fisheries could find no increase in flatfish abundance surrounding concrete reefs not placed in a semienclosed pattern[1]. The success of the horseshoe design should warrant attention to this pattern of placement in future reef construction.

Additional research could help determine what the relationship is between the size of the semienclosed space and the density of fish it will harbor. If adequate densities can be maintained within wider semicircles then there is less likelihood of entangling fishing gear.

This study was conducted along with a simultaneous assessment of the species associated with the tire reef structure itself (Walton, 1979). In addition to the six species of flatfish observed within the reef, 16 other species were noted on the reef at an average density of 0.72 fish/m^2 and a biomass of 53 g/m^2 during the day. This additional species assemblage results in an average of 203 fish being within the reef site compared with 28 fish before the reef placement.

The concerns of Hoese (1978) that artificial reefs which change the nature of the substrate and result in increases in reef population which might interfere with flounder production appear to be unfounded in the Puget Sound region and in fact the evidence strongly suggests that increases in fishes available to both flounder fishermen and reef fishermen can occur.

[1]Hueckel, G. J. 1981. Washington Department of Fisheries, Olympia. Pers. commun.

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Food of Fish Collected on Artificial Reefs in the New York Bight and Off Charleston, South Carolina

FRANK W. STEIMLE, Jr., and LARRY OGREN

ABSTRACT—The construction of artificial reefs is a popular means of countering increasing recreational fishing pressure. Despite their popularity, many questions persist about their function and effectiveness as a management tool. This paper discusses the role of the epifauna, which develops on artificial reefs and most other submerged hard surfaces, in providing food for the fish population found on or near artificial reefs. The stomach contents of 309 specimens of 13 species of fish, collected by spear or hook and line at three artificial reef sites, were examined to better define their trophic dependence on reef epifauna. Although most examined species did not appear to be highly dependent on the reef epifauna for food, there is a need for further study.

Introduction

Artificial reefs have been used for centuries to enhance or concentrate populations of aquatic organisms. The principle behind their use is that of providing or increasing one or more environmental factors, e.g., cover, food, or spawning grounds, which limit the potential development of these populations. In recent years U.S. use of artificial reefs has been mostly in recreational fishery management and has increased somewhat proportionately with the increase in fishing pressure and the decrease in coastal and estuarine environmental quality. With rising fuel costs, attempts to enhance fishing near to ports will surely include the construction of more artificial reefs.

Despite their use for several decades in the United States (Steimle and Stone, 1973), major questions about the dependency of fish on artificial reefs persist. With the probable increase in artificial reef construction, some clearer insights into the function of artificial reefs must be gained, to make intelligent and optimum use of this management tool. A question that has not received enough attention concerns the role of artificial reefs in increasing or improving the quality or quantity of forage for fish. Besides the obvious cover provided by artificial reefs, the hard surfaces of reef material are colonized by an encrusting community. If the fish inhabiting artificial reefs depend heavily on this community for food, this would further define the function of the reef in attracting and maintaining fish populations and would assist artificial reef designers to develop more effective and productive structures.

This study was conducted to address the question of whether artificial reefs are, or can be, important providers of forage for fish. The study was part of a more extensive investigation by the former Bureau of Sport Fisheries (now National Marine Fisheries Service, NOAA) on the construction, utilization, and effectiveness of artificial reefs (Parker et al., 1974; Stone et al., 1974).

Methods

The 309 stomachs from 11 species of fish (Table 1) used in this study were

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Table 1.—Summary of fish samples obtained for this study (names of fishes from AFS, 1970.)

Species		Number of samples obtained at:		
Common name	Scientific name	Atlantic Beach, N.Y.	Monmouth Beach, N.J.	Charleston, S.C.
Atlantic cod	*Gadus morhua*	32		
Red hake	*Urophycis chuss*	15	16	
Rock sea bass	*Centropristis philadelphica*			8
Black sea bass	*Centropristis striata*		7	52
Sheepshead	*Archisargus probatocephalus*			3
Pinfish	*Lagodon rhomboides*			3
Scup	*Stenotomus chrysops*			3
Northern kingfish	*Menticirrhus saxatilis*	23		
Tautog	*Tautoga onitis*	43	14	
Cunner	*Tautogolabrus adspersus*	39	48	
Winter flounder	*Pseudopleuronectes americanus*		3	

Table 2.—Locations and characteristics of the three artificial reefs where fish were collected.

Reef site	Location	Date established	Depth (m)	Characteristics
Charleston	13 km east of Keawah Island, S.C.	October 1967	15	70 car bodies placed on a sandy bottom.
Monmouth Beach	3.25 km east of Monmouth Beach, N.J.	August 1966	15-18	16 car bodies, 20 pyramidal 12-tire units, and 1,100 single tire units on a sandy bottom. Rounded outcroppings of rock with patches of sand, shell, and cobbles were nearby.
Atlantic Beach	5.5 km south of Atlantic Beach, N.Y.	July 1967	20	404 car bodies, one metal and one wooden barge placed on a sandy bottom.

Table 3.—Food of fish collected on the Charleston, S.C., artificial reef, presented as percent of total volume of stomach (S) and intestine (I) contents.

	Predator									
	Black sea bass		Rock sea bass		Scup		Pinfish		Sheepshead	
Prey	S	I	S	I	S	I	S	I	S	I
Chaetognatha					50.0					
Mollusca (unidentified)	<1.0									
Solen sp.	6.1	3.9	2.9	4.1				16.7		
Polychaeta	<1.0	5.4								
Crustacea										
Cirripedia	5.0	10.1							20.5	27.5
Cumacea	<1.0	<1.0				93.3	33.3	20.8		
Isopoda	<1.0	<1.0								
Amphipoda	10.9	16.4		2.7			66.7	62.5	4.0	8.6
Decapoda (unidentified)	3.4	7.2		42.5						
Brachyura (unidentified)	12.4	13.5	7.7	13.7	50.0					
Cancridae	<1.0	2.5	2.9							
Portunidae	37.4	5.2	36.5	5.5						
Xanthidae	<1.0	2.3	24.0	5.5						
Tunicata	<1.0	1.2							67.6	21.4
Pisces	11.7		26.0							
Unidentified organic matter	4.9	38.6		26.0		6.7			6.8	42.0
Number of predators examined	52		8		3		3		3	
Number of empty guts (S + I)	2		0		1		0		0	
Mean predator fork length (cm)	13.7		15.6		8.9		10.2		29.5	

collected at three artificial reef sites: Off Charleston, S.C.; Monmouth Beach, N.J., and Atlantic Beach, N.Y. The characteristics of each site are presented in Table 2. Fish samples were collected by diver-held spear at the Charleston and Monmouth Beach sites, and by hook and line at the Atlantic Beach site. These two methods were used to overcome the difficulty in obtaining samples of reef fish by more standard methods (i.e., trawling and bottom longlines) because of the problem of hanging up. Hand spearing also allows the collector to observe whether any food material is regurgitated. Regurgitation, because of rough handling (i.e., within the cod end of a trawl), could be a very important source of error as well as in the use of baited hooks on longlines in food habits studies. The disadvantage of the chosen sampling methods is that they produce small quantities of samples per unit effort than other methods, thus the relatively small number of samples examined in this study. Collections were made primarily between late spring and early fall (except for several winter collections at the Atlantic Beach site) from 1967 through 1970. The species and number of individuals per species were determined by what was actually caught by hook and line or speared by the divers, who tried to select their targets at random and to be representative of dominant species present. Stomachs and intestines were quickly removed from all fish samples and preserved in 10 percent buffered formalin. In the laboratory, the total volume of the contents as well as the volume of each identifiable food item were determined for the contents of the gut (stomach and intestine) of each fish.

Results and Discussion

The results of the gut content analysis of the five most commonly sampled species for each study site are presented in Tables 3-5. These results provide little concrete evidence to support the hypothesis that most fish species found in, on, or adjacent to temperate artificial reefs are present because of a high dependence on the reef-associated fauna or flora for food. Faunal groups or species that are, without a doubt, closely associated with reefs, e.g., hydroids, mussels

Table 4.—Food of fish collected on the Monmouth Beach, N.J., artificial reef, presented as percent of total volume of stomach (S) and intestine (I) contents.

	Predator									
	Red hake		Black sea bass		Tautog		Cunner		Winter flounder	
Prey	S	I	S	I	S	I	S	I	S	I
Hydrozoa	<1.0				7.3	2.2	8.0	1.4		
Bryozoa						2.7				
Mollusca (unidentified)		4.3					<1.0			
Mytilus edulis					9.1	35.1	31.5	49.5		
Cephalopoda			7.7							
Polychaeta (unidentified)					4.7		9.6	<1.0	16.7	2.7
Nereis sp.	2.9	2.4							83.3	8.1
Crustacea										
Cirripedia								<1.0		
Copepoda							1.0	2.8		
Cumacea							1.3	<1.0		
Amphipoda	<1.0	<1.0					2.0	1.0		
Mysidacea							<1.0	1.4		
Decapoda (unidentified)		22.7	61.5				<1.0	8.8		
Caridea (unidentified)	<1.0	5.3					1.0	6.5		
Crangon septemspinosus	11.1						2.6	3.7		
Brachyura (unidentified)	2.6	16.3			3.6		18.2	3.2		
Cancer spp.	32.7	1.1	30.8	11.1	27.5	54.1	6.6			
Echinodermata										
Echinarachnius parma					37.8			3.2		
Tunicata	44.3	1.1								
Pisces	3.5						4.0	1.9		
Unidentified organic matter	1.6	47.1		88.9	10.0	5.9	12.3	14.8		89.2
Number of predators examined	16		7		14		48		3	
Number of empty guts (S + I)	2		3		0		11		0	
Mean predator fork length (cm)	33.1		21.9		23.0		15.8		23.1	

(*Mytilus*), barnacles (cirripedia), and possibly tunicates, occurred in the guts of most species examined but only exceeded 25 percent of total stomach or intestine volume in three species: Tautog, cunner, and sheepshead. Barnacles comprised 37 percent of the total intestinal volume of Atlantic Beach tautog, while *Mytilus* comprised 35 percent of the intestinal volume of Monmouth Beach tautog. *Mytilus* also comprised over 40 percent of cunner intestinal volume at both Atlantic Beach and Monmouth Beach sites. However, tautog stomach contents, reflecting more recent feeding, indicate that *Cancer* crabs and sand dollars, *Echinarachnius parma*, were as or more commonly selected. Also, the stomachs of cunner contained both *Mytilus* and *Crangon septemspinosus*, the sand shrimp (a sandy sediment inhabitant), as major constituents. The separation of stomach and intestine in the cunner may be a moot question as Chao (1973) points out. The few sheepshead examined at the Charleston site showed the highest reef dependence, assuming the tunicates were the encrusting type, with most (88 percent) of the stomach and half (49 percent) of the intestinal volume comprised of barnacles and tunicates.

Full identification of most of the items found in the fish guts was impossible or impractical (tediously comparing microscopic fragments to a type set of many possible items). Thus, there is a good chance that some of the other material found in the guts could have been other species also closely associated with the reef's encrusting or epifaunal invertebrate community, e.g., the Xanthid crabs in the diets of rock sea bass at the Charleston site or the amphipods preyed upon by northern kingfish at the Atlantic Beach site. This could possibly increase our assessment of reef dependence, but we can only speculate at this point.

On the other hand, the large amount of identifiable material most probably consumed on the adjacent, nonreef sediments made apparent the opportunistic nature of most fish collected in the study. These nonreef food items, including chaetognaths, the razor clam (*Solen*), cumacea, portunid crabs, nerid polychaetes, *Crangon* shrimp, and sand dollars, *E. parma*, comprised major portions of the diets of most of the fish examined. Other important diet items, e.g., *Cancer* crabs and fish, could have potentially been preyed upon on or off the reef habitat and thus cannot provide any insight into the forage function of artificial reefs.

Other studies which have examined the food habits of the species in our study indicate similar results. For example, Chao (1973) and Shumway and Stickney (1975) indicated that barnacles (*Balanus*) and *Mytilus* were generally the dominant prey of cunner in southern New England waters. Olla et al. (1975) report *Mytilus* to be the most frequently occurring food in the digestive tract of

Table 5.—Food of fish collected on the Atlantic Beach, N.Y., artificial reef, presented as percent of total volume of stomach (S) and intestine (I) contents.

Prey	Predator									
	Atlantic cod		Red hake		Northern kingfish		Tautog		Cunner	
	S	I	S	I	S	I	S	I	S	I
Hydrozoa							<1.0		5.7	3.3
Gastropoda	2.3									
Bivalvia (unidentified)	1.0						<1.0	2.1	2.5	
Mytilus edulis		<1.0					3.4		16.5	42.9
Solen sp.									2.9	
Polychaeta (unidentified)		6.7	<1.0		17.1	11.6	<1.0			
Nereis sp.	3.9	<1.0			46.5	11.5				
Flabelligeridae	<1.0		1.5				<1.0			
Polynoidae					1.2					
Glyceridae					2.4	4.3				
Crustacea										
Cirripedia							<1.0	37.2		
Amphipoda		<1.0			15.3	23.2	<1.0		<1.0	
Mysidacea									2.5	1.1
Decapoda (unidentified)			<1.0	4.1			<1.0			
Homarus americanus	1.3									
Caridae (unidentified)	<1.0	2.0	<1.0	3.3						
Crangon septemspinosus	5.7	<1.0	93.3	30.8	2.7				39.0	37.4
Pandalus sp.									<1.0	2.2
Anomura	1.9									
Brachyura	<1.0	24.4		4.3			6.7	23.4	24.1	4.4
Cancer sp.	55.8	8.0	2.7		7.3		78.2		<1.0	4.4
Pisces	27.7	<1.0	<1.0						1.6	
Unidentified organic matter		56.4	1.0	57.5	7.3	49.3	8.6	37.2	3.2	4.4
Number of predators examined	32		15		23		43		39	
Number of empty guts (S + I)	2		1		0		11		5	
Mean predator fork length (cm)	59.5		35.6		25.1		29.1		19.3	

tautog in their Long Island, N.Y., study. Bigelow and Schroeder (1953) and Kendall (1977) reported that black sea bass were opportunistic benthic omnivores, with the adults subsisting chiefly on decapod crustacea, fish, and some mollusks. The classification "opportunistic benthic omnivore" also generally fits the remaining species in this study and agrees with other food habit reports in the literature, e.g., Bigelow and Schroeder (1953).

In conclusion, this study suggests that few fish species found around Atlantic temperate artificial reefs during the study period are obligated for sustenance to the encrusting or attached epifaunal forage species that develop on the hard surfaces of artificial reef habitats. Other artificial reef studies in temperate or warmer waters (Randall, 1961; Russell, 1975) also suggest that, generally, reef-dependent food resources may be less important in attracting and accommodating fish populations than shelter or other behavioral requirements provided by the reef structure. Olla et al. (1975) indicate that even for the tautog, which preys primarily on mussels commonly found attached to hard surfaces such as artificial reefs, the necessity for shelter may be the limiting factor in its population size.

The results of this study are far from conclusive. Additional studies should be designed that would also examine factors such as the quantity of forage available on artificial reefs compared to that of the adjacent bottom, or the food habits of juvenile fishes collected on reefs. This type of information is essential in designing and planning effective artificial reefs and making them a more useful fishery management tool.

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Early Development of Pendleton Artificial Reef

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Introduction

Construction of the Pendleton Artificial Reef (PAR) (Grove, 1982) offered the California Department of Fish and Game (CDFG) and Southern California Edison (SCE) an opportunity to utilize several techniques in an attempt to enhance an otherwise relatively unproductive environment and to investigate the potential of such reefs as a mitigation measure for potential damage to the nearshore marine environment by a coastal power plant. Of particular interest is the transplantation of giant kelp, *Macrocystis pyrifera* and *M. angustifolia*, to the reef. Establishment of a stand of giant kelp will increase the aspect-ratio of the reef and provide "substrate to surface" habitat for fish and invertebrate species.

Site Selection

Several criteria were used to determine the location for PAR construction. Water depth was chosen as being adequate for *Macrocystis* growth and recruitment in that section of coast. This decision was based upon experience gained in kelp restoration work and dives in nearby kelp forests to assess local conditions. Sites that were heavily influenced by terrestrial runoff were rejected in an effort to avoid excessive turbidity, siltation, and substrate burial. Since the reef was to be constructed on sand, excavations and probes were made to determine if a solid base was present. A site which was mutually agreeable to CDFG and SCE was selected; however, this was changed since the presence of an artificial reef in that location could impact ongoing studies to determine the effect of San Onofre Nuclear Generating Station (SONGS) on local biota. The site was moved further down the coast to its present location 5.5 km (3.4 miles) southeast of SONGS in 13.1 m (43 feet) of water (Fig. 1).

Design and Construction

Many materials have been used to construct artificial reefs. Turner et al. (1969) concluded that concrete shelters attracted the greatest number of fishes. However, they also found that man-made reefs caused continual bottom sediment disturbances with alternate "sanding in" and scouring of the lower edge of the reef. This effect is somewhat lessened on quarry rock reefs, and allowances for this scouring action were incorporated into our reef design. After considering all facts, including lower cost and ease of handling, we designed the reef to be constructed of quarry rock.

Many Japanese reef designs have served to attract, or centralize, finfish assemblages for harvest by achieving high relief or "high-aspect ratios." While increasing the potential for exploitation of finfish populations is not the main purpose of PAR, we did incorporate high relief into the design to provide habitat above the effects of siltation for settlement and growth of *Macrocystis*. The aspect-ratio will be further enhanced by growth of *Macrocystis*.

A phenomenon known as the "edge effect" (Odum, 1971) is also incorporated into the design of this reef. Turner et al. (1969) suggested that reef design should incorporate large open spaces 50-60 feet (16-18 m) in diameter. The horizontal configuration of the reef as designed is presented in Figure 2. The reef was designed to consist of eight modules, each 27 m (90 feet) long, 12 m (40 feet) wide, and 3.1 m (10 feet) high, placed 18 m (60 feet) apart. The sandy areas are expected to enhance the edge effect wherever they adjoin the rock piles and the spacing is such that the piles will act as one large reef rather than eight discrete reefs.

Recent work by Tegner[1] indicates that abalone, *Haliotis* sp., recruitment may be enhanced by the presence of cobble-sized rock. Consequently, four of the modules received a "topping" of such

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ABSTRACT—An artificial reef was constructed of 9,100 t (10,000 tons) of quarry rock, in southern California, 1.6 km (1 mile) offshore of Camp Pendleton. The reef was arranged in eight high-relief modules covering 2.8 hectares (7 acres) of sand substrate in 13.1 m (43 feet) of water. Management techniques are being utilized in an effort to accelerate and direct successional changes on the reef. These have included transplanting giant kelp, Macrocystis *spp., and red abalone,* Haliotis rufescens. *Successional changes and the impact of management operations on the reef were monitored. After 1 year 19 species of fishes and 26 species of invertebrates were observed.*

[1]Mia Tegner, Scripps Institution of Oceanography A-001, La Jolla, CA 92093. Pers. commun.

rock. Future abalone recruitment on modules with and without the topping can thus be compared.

The reef was constructed of 9,100 t (10,000 tons) of rock from the Connolly-Pacific[2] quarry near Avalon on Santa Catalina Island. Although rocks ranged from 0.3 to 2 m (1-6 feet) in diameter, rocks of 0.6-1.3 m (2-4 feet) diameter form the main body of all modules except Module 3, which is composed entirely of 1.3-2.0 m (4-6-foot) rocks.

The construction contractor was unable to place the rock exactly as planned due to adverse seas occurring during construction. However, the resultant configuration (Fig. 3) has proven adequate.

[2]Mention of trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

Establishment of Ecological Studies

Considerable time was spent setting up transect lines for ecological surveys. Lead-core 30 m (98.4-foot) lines marked at 1 m intervals were laid out along longitudinal and latitudinal axes of all eight modules (Fig. 2). These 1 cm (⅜-inch) diameter lines are permanent transect markers. Physical parameters such as depth and substrate composition were noted at 5 m (16.4-foot) intervals along all lines. Movement of permanent transect lines has been minimal even under conditions of heavy surge. The only losses have apparently been related to the settling of rocks during heavy seas in winter 1980-81 and to the dragging of boat anchors.

Preliminary diving surveys to determine species composition and abundance of fishes were conducted in November and December 1980 using rapid-visual survey techniques (Jones and Thompson, 1978). Qualitative observations of species composition and relative abundance of fishes have been made frequently during all diving activities on PAR.

Quarterly studies, beginning in August 1981, included random 0.25 m^2 quadrat surveys of all biota and 30×1 m band surveys of selected invertebrates and algae along the permanent lead-core lines.

Preliminary analysis of data collected from random 0.25 m^2 surveys indicated that the variance of fauna sampled was such that our sampling effort would have to be much greater if our data were to have statistical validity. Consequently we initiated a sampling program utilizing an 0.125 m^2 Random Point Contact (RPC) method. This technique, popular in terrestrial plant ecology (Winkworth, 1955), was adapted to subtidal-sampling needs by personnel of Lockheed Ocean Science Laboratories[3] and modified to fit the requirements of our program.

Reef Biomanipulations and Management

Such operations in 1980-81 included the transplantation of giant kelp and juvenile red abalone, *Haliotis rufescens*, onto PAR. Three separate kelp-transplanting operations were conducted in October-November 1980 and April, May, and June 1981.

During the first operation, subadult and young adult plants were obtained from Neushul Mariculture in Santa Barbara and approximately 36 of these were transplanted onto Module 6 in November 1980. They also provided several bricks

Figure 1.—Location of the Pendleton Artificial Reef.

[3]John W. Carter, Lockheed Ocean Science Laboratories, 6350-A Yarrow Drive, Carlsbad, CA 92093.

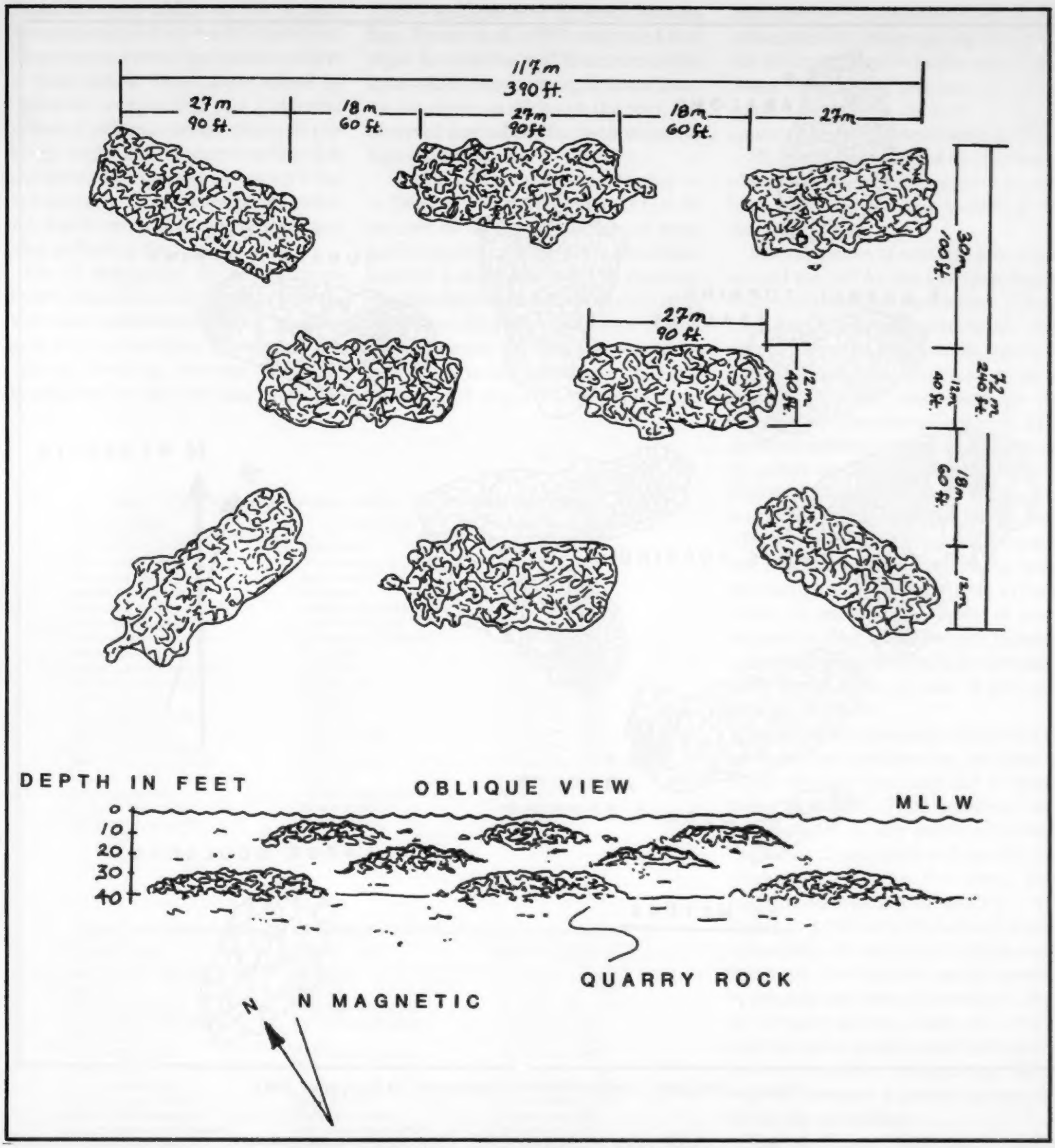

Figure 2.—Pendleton Artificial Reef as designed, 23 June 1980.

filled with Osmocote time-release fertilizer to which young *Macrocystis* plants were attached. These were also placed on Module 6. Twenty-five additional young *Macrocystis* plants were collected from San Mateo Point and SONGS kelp, and transplanted to Modules 6 and 8 in April 1981.

To further increase the standing crop of *Macrocystis* plants on the reef to provide parent stock, and to protect offspring from fish-grazing damage, one additional kelp transplanting effort was made at the end of May and early June 1981. A total of 300 kelp plants was collected from Abalone Cove on Palos Verdes Peninsula in Los Angeles County and transplanted to the remaining six

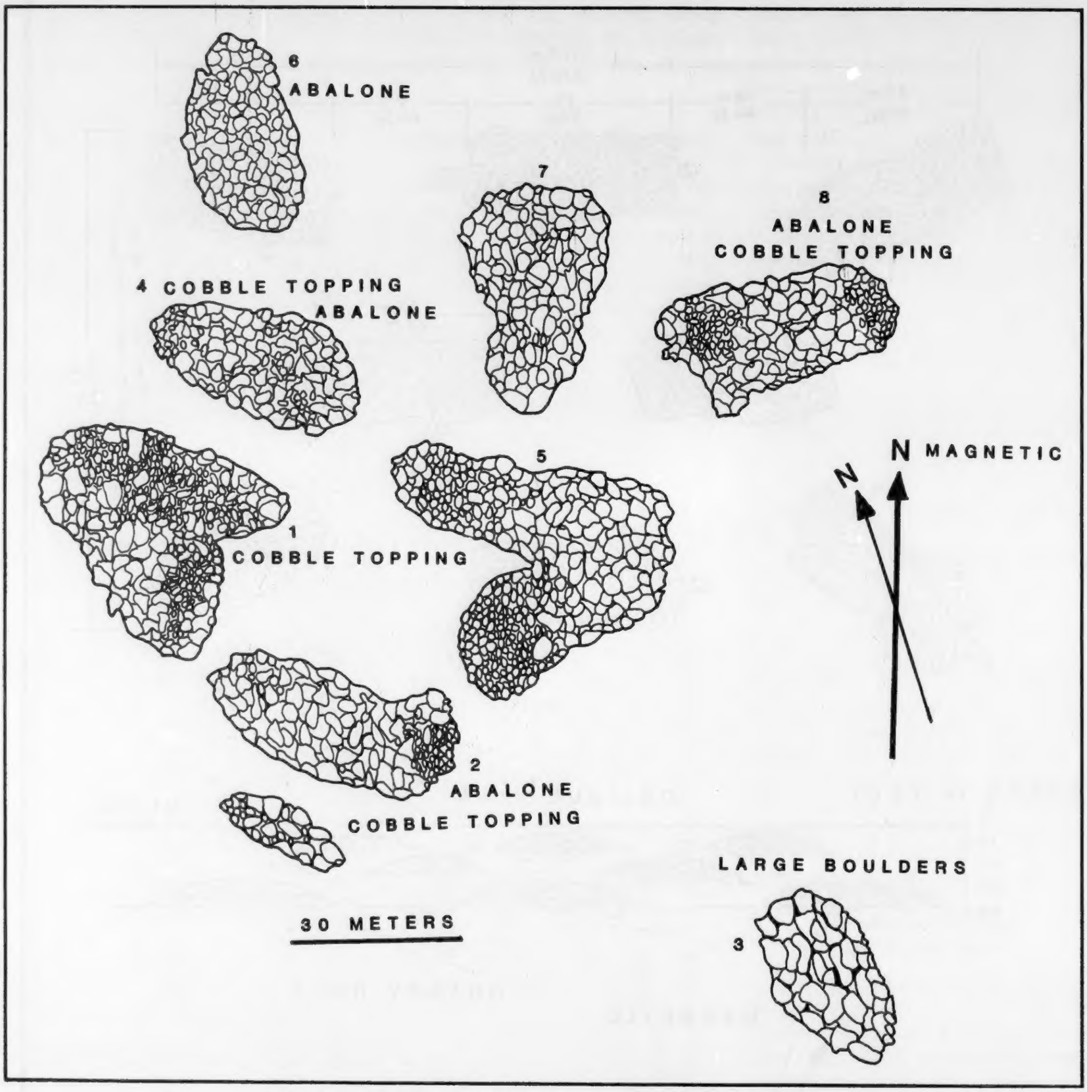

Figure 3.—Pendleton Artificial Reef as constructed, 24 September 1980.

modules, 1 through 5 and 7, during 3 days of field operations.

The first transplant of red abalone took place in July 1981. A total of 825 juvenile (2-4.5 cm) red abalone was placed on Module 8 during one transplant operation.

Biological Observations

No formal surveys of reef biota were made prior to August 1981. However, early biotic development was noted during general working or reconnaissance dives. Results of these informal observations, discussed below, are given in Tables 1 and 2.

Reef construction began on 27 August 1980. Reconnaissance dives the next day revealed several black perch and white seaperch. Barred sand bass and kelp bass were present. These fishes were not unexpected. Turner et al. (1969) and Carlisle et al. (1964) noted the presence of such fishes within hours of reef construction in Santa Monica Bay. These species are adventitious feeders who characteristically can cover large areas while foraging for food. The dumping of so much rock and subsequent perturbation of the bottom possibly exposed food

organisms upon which the fish preyed. Reconnaissance dives made 5 days later, 2 September, showed increased numbers of these fishes. These were joined by California scorpionfish and California halibut. California scorpionfish are primarily rock- and crevice-dwelling fish and were not expected to colonize the reef so early in its development since they had to cross large expanses of sand prior to finding the rocks.

On 17 September the first obvious invertebrates were noted. Large numbers of juvenile barnacles were seen covering most exposed surfaces. Numerous colonies of *Obelia* sp. were also abundant. Identifiable for the first time were the CDFG artificial reef in Santa Monica Bay. Turner et al. (1969) suggested that algae *Ectocarpus* and filamentous diatoms which were growing in abundance on the upper portions of the reef. We observed four adult *Pisaster brevispinus* high on the modules.

During kelp transplanting operations in October 1980, we estimated that 80 percent of the upper surface of most rocks was covered by a 1-2 mm thick layer of a sticky clay-silt-like material. This was later identified as the encrusting ectoproct *Cryptoarachnidium argilla*. This organism was first observed as covering most hard surfaces in the early successional stages of the biota on a thick layers of this organism could inhibit colonization by other species. However, this did not appear to be the case in the Santa Monica Bay reef and, as subsequent observations indicate, it doesn't appear to be an inhibiting factor on PAR.

We noted that many of the barnacles observed earlier had been broken, perhaps either by fish and starfish or by dragged boat anchors.

Several species of new fish were noted around the reef for the first time during kelp transplanting operations. These included California sheephead, pile perch, halfmoon, blacksmith, opaleye, garibaldi, and what appeared to be a juvenile giant sea bass, which are becoming rare in southern California. This apparent sighting, subsequently followed by others on 20 October 1980 and 31 March 1981, suggests juvenile giant sea bass may become residents of the reef. The area from Dana Point to Oceanside has historically been one of the most productive giant sea bass areas in California. A resident population of giant sea bass on PAR would be very valuable and would present significant management implications in view of their decreasing numbers.

Garibaldi are generally considered to be a resident species that establish a home territory and tend not to leave unless displaced. Their presence, and the presence of the previously-noted California scorpionfish indicate the beginnings of a resident fish fauna. This has been described by other CDFG biologists in previous artificial reef work. Apparently, the early stages of the reef's fish fauna development are dominated by perches and basses that move in during foraging activity. Later, as a more complex fauna develops and more niches become available, resident-type fishes begin to compose a greater component of the fish assemblage.

The numbers of fish present during early October dives were tremendous. Sublegal kelp and barred sand bass surrounded some modules in numbers that were close to uncountable. Fishes appeared to be most abundant on the northwesterly modules, and became progressively less abundant on modules to the southeast. Sportfishing boats from Dana Point were regularly observed

Table 1.—Fish Observed on Pendleton Artificial Reef (in order of observation).

Scientific Name	Common name	Date of first observation
Embiotoca jacksoni	Black perch	28 August 1980
Phanerodon furcatus	White seaperch	28 August 1980
Paralabrax nebulifer	Barred sand bass	28 August 1980
Paralabrax clathratus	Kelp bass	28 August 1980
Scorpaena guttata	California scorpionfish	2 September 1980
Paralichthys californicus	California halibut	2 September 1980
Semicossyphus pulcher	California sheephead	17 October 1980
Rhacochilus vacca	Pile perch	17 October 1980
Medialuna californiensis	Halfmoon	17 October 1980
Chromis punctipinnis	Blacksmith	17 October 1980
Girella nigricans	Opaleye	17 October 1980
Hypsypops rubicundus	Garibaldi	17 October 1980
Stereolepis gigas	Giant sea bass	17 October 1980
Anisotremus davidsoni	Sargo	17 October 1980
Halichoeres semicinctus	Rock wrasse	17 October 1980
Scorpaenichthys marmoratus	Cabezon	11 December 1980
Oxylebius pictus	Painted greenling	May 1981
Sebastes auriculatus	Brown rockfish	May 1981
Cheilotrema saturnum	Black croaker	May 1981

Table 2.—Invertebrates Observed on Pendleton Artificial Reef (in order of observation).

Scientific name	Common name	Date of first observation
Megabalanus californicus	Barnacle	17 September 1980
Obelia sp.	Hydroid	17 September 1980
Pisaster brevispinus	Short-spined sea star	17 September 1980
Cryptoarachnidium argilla	Encrusting ectoproct	17 October 1980
Abietinaria sp.		22 October 1980
Pisaster giganteus	Giant-spined sea star	30 October 1980
Spirorbis sp.		11 December 1980
Membranipora sp.		11 December 1980
Panulirus interruptus	Spiny lobster	12 December 1980
Styela montereyensis	Stalked tunicate	16 January 1981
Aglaophenia struthionides	Ostrich-plume hydroid	16 January 1981
Pododesmus cepio	Abalone jingle	16 January 1981
Chaetopterus variopedatus	Parchment tube worm	16 January 1981
Salmacina tribranchiata		31 March 1981
Loxorhynchus crispatus	Sheep crab	31 March 1981
Diplosoma macdonaldi		21 April 1981
Cystodytes lobatus		21 April 1981
Dendrobeania laxa		20 May 1981
Serpulorbis squamigerus	Scaled worm shell	20 May 1981
Corynactis californica	Strawberry anemone	20 May 1981
Tubularia crocea		20 May 1981
Octopus sp.	Octopus	20 May 1981
Chelyosoma productum	Ascidian	August 1981
Plumularia sp.	Hydroid	August 1981
Hinnites giganteus	Purple-hinged scallop	August 1981
Notoacmaea sp.	Limpet	August 1981

fishing the reef.

Sargo were first noted on the reef on 21 October 1980. Commercial lobstermen were working PAR, with two individuals working nine traps. We observed the first rock wrasse the following day. Also noted for the first time was a lone *Abietinaria* sp. colony. The dive on 30 October 1980 produced our first sighting of *Pisaster giganteus*, a starfish common on most southern California rocky substrate out to 18 m (60 feet) deep.

On 11 December, a reconnaissance of Module 7 revealed the presence on occasional rock surfaces of an encrusting bryozoan, *Dendrobeania* sp. A minute prostrate polysiphonous red algae with a finely-divided thallus was observed forming numerous 2.5-5 cm (1-2 inch) diameter patches on upper rock surfaces. *Enteromorpha* was noted on the upper 1.5 m (5 feet) of Module 7. A reconnaissance of the *Macrocystis* transplants on Module 6 indicated that 26 of the original 36 plants had survived. Most were in poor condition with *Spirorbis* and *Membranipora* heavily epiphytic on the blades. Little new frond growth was evident on any plants except those attached to the Osmocote-filled bricks. Of the 26 remaining transplants, 16 had some hapteral attachment to the rock. Poor growth of plants, except for those on the Osmocote bricks, was probably the result of high temperatures and low nutrient levels. Plants on the bricks constantly bathed in nutrients escaping from the Osmocote did better than other transplants. One large kelp plant, with 12 fronds, greater than 1 m in length and with sporophyll development, was lodged in the lower reaches of the reef. The holdfast of this plant had several large cobbles attached to it. The next day the first observations of a cabezon and a California spiny lobster were made.

The 6 January 1981 dive revealed that transplanted *Macrocystis* had produced new blades. Patches of red algae had become more dense and conspicuous with some areas up to 0.6 cm (¼ inch) thick. Incidental observations made on 16 January revealed several additional species. Good numbers of juvenile stalked tunicates were noted in many locations. They were particularly evident on our transect leadlines. The ostrich-plume hydroid, *Aglaophenia struthionides; Pododesmus cepio;* and a serpulid tube were also noted for the first time. Parchment tube worms, *Chaetopterus variopedatus*, were common under rocks.

Several new algal taxa were noted during this dive. These included an unidentified fleshy brown algae (possibly *Taonia* sp. or *Pachydictyon* sp.) an unidentified low-growing green algae, and *Colpomenia* sp.

On 31 March two juvenile giant sea bass were observed. Three small *Salmacina tribranchiata* colonies and a large sheep crab also were noted.

Three days of diving in April were dedicated to transplanting *Macrocystis* taken from San Mateo Point and SONGS kelp beds. In all, 25 plants were attached to the reef during these dives. Most were small with 1 or 2 fronds. About 12 of the original October 1980 transplants had survived. All mature growth was heavily grazed and epiphytized. New growth was no more than 0.3 m (12 inches) high and had few epiphytes. For the first time *Macrocystis* recruitment was observed on PAR by CDFG and Lockheed biologists. Juveniles were growing directly on the rocks at a depth of 10.4 m (34 feet). One area had seven juveniles 2.5-5.0 cm (1-2 inches) in height. This was encouraging since natural recruitment is vital for a stable, self-sustaining kelp bed and these findings indicated *Macrocystis* would recruit on the reef. These plants were subsequently grazed down by herbivorous fishes. This has often occurred in our kelp restoration work and can be overcome by transplanting a large number of adults to provide a sufficient biomass to overcome the detrimental effects of fish grazing.

Other algae had become increasingly obvious on the reef. *Rhodymenia* sp. was abundant on most of the higher rocky areas, as was minute polysiphonious red algae and occasional *Enteromorpha.* One of the Osmocote bricks was covered with juvenile *Eisenia.* These plants were not present during the original transplant operations and the bricks had not been in the water prior to our use. It seems likely, therefore, that the plants recruited in situ. This suggests that survival of these plants was enhanced by the increased nutrients since they were not noted on any other part of the reef. Two colonial ascidians, *Diplosoma macdonaldi* and *Cystodytes lobatus,* were noted.

Four new fishes were observed during May transplant operations. These were the painted greenling, brown rockfish, black croaker, and an unidentified surfperch.

Many fishes were living within the reef, going into crevices and under rock overhangs. In many ways, the rock mix appeared to provide more habitat for fishes than did the concrete shelters in the Hermosa Artificial Reef in Los Angeles County. A 0.6 m (2 foot) long California halibut was observed resting on top of a large, flat, horizontal rock near the crest of Module 3. This was significant since the halibut was more than 3.0 m (10 feet) above its normal habitat on the sand. This was the second occurrence of this behavior noted at PAR.

Of interest was the discovery of two very old and blackened *Macrocystis* holdfasts on bedrock exposed at the base of the reef by scouring action. The bedrock was also pockmarked with holes of boring clams suggesting an extended interval of exposure at some time in the past.

During reconnaissance dives in May, *Serpulorbis squamigerus, Tubularia crocea, Corynactis californica,* and one *Octopus* sp. were observed.

The first formal surveys of reef modules took place during the first two weeks of August 1981. However, preliminary evaluation of data from these surveys suggests that the dominant invertebrate, in terms of substrate covered was *Cryptoarachnidium argilla.* This organism, which incorporates sediment in a tubule network, covered between 70 and 100 percent of rock surfaces. The most conspicuous invertebrates were several species of barnacles, most numerous of which was *Megabalanus californicus.* Small hydroids, notably *Plumularia* sp. and *Obelia* sp. were also common, particularly in protected areas. New species of invertebrates noted during the August sampling period were the ascidian, *Chelyosoma productum;* the purple-hinged scallop, *Hinnites giganteus;* and an immature *Notoacmaea* sp.

Low growing vegetative cover, composed of *Ectocarpus, Gigartina, Polysiphonia,* and *Rhodymenia,* was abundant, covering up to 95 percent of some rock surfaces. Vegetation did not appear to be negatively impacted by the *Cryptoarachnidium* cover because algae were growing on and through this ectoproct/silt layer. *Macrocystis* haptera also appear to penetrate *Cryptoarachnidium* and attach to rock.

Discussion

Pendleton Artificial Reef, 1 year after construction, appears to have developed a complex assemblage of fishes, invertebrates, and algae. The individual modules are very similar to "Toseki" or "artificial shoals" which, in Japan, are designed to enhance production of a variety of species.

Maximum enhancement of PAR depends, in our opinion, on establishment of a *Macrocystis* bed on the modules. *Macrocystis* beds are complex communities which have been compared in dimension and complexity to terrestrial rain forests (Foster, 1975a, b). The presence of a *Macrocystis* bed greatly increases the numbers and diversity of fish and invertebrate populations. Quast (1968), referring to *Macrocystis,* stated: "In regions with similar rocky substrates of low or moderate relief, the areas with kelp give estimates of the standing crop of fishes that is two to three times as great as that of similar habitats barren of kelp" (sic). A similar situation has been reported by North (1964). Regarding plant biomass he stated: "The standing crop of benthic algae in an open area may be seven times that existing below a *Macrocystis* canopy, but if *Macrocystis* were included, the standing crop of plant material was three to four times as great within the bed as outside."

The desirability of *Macrocystis* is evident. We designed and situated PAR primarily with the establishment of a *Macrocystis* bed as a desired final result. Attaining a stable bed on an artificial reef has not yet been accomplished. *Macrocystis* recruited naturally to an artificial reef constructed by the CDFG off Hermosa Beach in Los Angeles County. This bed was lost, probably due to poor water quality in the area and excessive depth. *Macrocystis* recruited to Torrey Pines artificial reef in 40 feet of water near La Jolla in San Diego County. This kelp bed was lost to sea urchin grazing, but has since begun to return after removal of the sea urchins.

Shoreline development and activities of the Marine Corps at nearby Camp Pendleton have all contributed to increased erosion along a broad section of that coast. At the reef site, substrate is composed of layers of terrestrial debris, sand, and broken shells approximately 2 feet thick overlaying a firm basement of rock and cobble. The placement of the reef, subsequent scouring around the edges of the modules, and increased movement of water between the modules, has removed large volumes of sand. The presence of numerous old blackened holdfast remains from an extinct kelp forest suggest that the probability of kelp recruiting to the area is excellent. We noted on early dives many *Macrocystis* recruits on the base of several modules. These were probably offspring of adult plants that drifted through and became temporarily entangled in the reef. Several of the plants we placed on the modules produced young, but the plant biomass was insufficient to protect these recruits from fish-grazing mortality.

The year 1981 was characterized by abnormally warm water conditions in the southern California bight which led to a decline in kelp beds along portions of the coast. Consequently, our transplants have not done as well as hoped. Perhaps 30 percent of the original plants survive. These, and transplants in October 1981 will, hopefully, form the nucleus for the 1982 parent stock.

The invertebrate fauna has progressively become more complex. The ubiquitous *Cryptoarachnidium argilla* appears to present little problem to many species. When it matures and thickens, it often becomes dislodged and portions fall away leaving exposed bare rock which can be colonized by other forms. Establishment of substrate-grazing invertebrates, such as sea urchins and sea cucumbers, may also help control the growth of *Cryptoarachnidium.*

Juvenile abalone, transplanted to the reef earlier, have suffered some mortality due to predation. However, recaptured individuals have shown new growth. The development of large brown algae, such as *Macrocystis,* is imperative to provide forage for the growing abalone.

Fish assemblages have, at times, exceeded our expectations. Extremely high numbers of basses and perches have been observed on every dive. There appears to be a cyclical increase in the numbers of large sand bass and kelp bass. The larger individuals of these species appeared in great numbers in September 1980 and August 1981. Similar observations were made at artificial reefs in Santa Monica Bay. Turner et al. (1969) suggested that these movements were related to spawning activities.

It is possible that, in its transitional phases of development, an artificial reef attracts a higher percentage of adventive peregrine fishes than mature reefs. Evidence supporting this is found in Turner et al. (1969) where it is reported that fishes, particularly embiotocids and serranids, appeared within hours after reef construction in Santa Monica Bay, and that these species dominated each reef's fish population during its first year. This dominance decreased during the second and third years as resident "reef species," such as gobies, cottids, and rockfishes, became more numerous and the reefs approached equilibrium. A similar pattern can be observed at Pendleton Artificial Reef. Large numbers of perches and basses were observed immediately after construction. Only later did we observe occasional individuals of species that could be defined as "resident species," such as garibaldi, and brown rockfish. Ideally, the most productive reefs would include elements of both resident "reef fish" and semiresident adventitious populations.

The success of PAR as an environmental enhancement tool could benefit regulatory agencies, utility companies, and sport and commercial fishing interests. Results of the first year of a 5-year study indicate that the diversities of fishes, invertebrates, and algae are increasing. Algal cover is also increasing and naturally-recruited *Macrocystis* sporophytes have been noted. The final measure of the success of PAR will be in its comparison with natural reefs of similar configuration that occur nearby.

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National Marine Pollution Plan Seeks Ocean Dumping Studies

As waste increases and places to put it decrease, research into possible effects of more ocean dumping becomes urgent. So recommends the Commerce Department's National Oceanic and Atmospheric Administration (NOAA) in a National Marine Pollution Program Plan issued this spring.

The 5-year plan, required by the National Ocean Pollution Planning Act of 1978, finds that sewage waste disposal in particular is a growing problem as the population increases. "Pressure is mounting to allow continued and increased disposal of sewage sludge in the oceans," the plan says. It also calls for more study of ocean dumping of dredged material and industrial waste—much of which is toxic—to see how best such activities can be carried out.

To make waste management decisions, the plan says, a conceptual model to assess the risks and impacts of ocean dumping options should be developed, and applied in a specific region to assess its usefulness and the feasibility of a regional approach. The plan was drawn up by the Interagency Committee on Ocean Pollution Research, Development, and Monitoring.

An earlier 5-year plan was issued by the Committee in the fall of 1979. "The emphasis on municipal waste disposal in the new plan represents a substantial change from the first plan," said Anthony Calio, chairman of the committee and deputy administrator of NOAA. "This reflects a change in public attitude — ocean dumping is now considered by many to be preferable to land dumping. We must find ways to use the oceans effectively as a waste repository."

The plan also recommends that some Outer Continental Shelf oil and gas leasing research be diverted from pre-lease environmental studies to post-lease monitoring, aimed at measuring the subtle effects of oil and gas activities conducted over long periods of time. Federal research on petroleum pollution in the marine environment represents about 25 percent of the total Federal expenditure. An interagency planning group is being formed to coordinate the long-term monitoring program.

Other relatively high priority areas listed by the plan are accidental discharges of oil and hazardous materials, nonpoint source pollution (such as agricultural runoff), and increased coal use as an emerging problem (disposal of fly ash and related activities will cause mounting problems as coal use is increased).

Areas of relatively low priority in the context of national marine pollution problems—either because they do not pose problems or because the problems are being adequately addressed—are brine disposal, sand and gravel mining, deep seabed mining, and ocean-thermal energy conversion.

Magnetite Is Magnetic Material in Tuna Skulls

A University of Hawaii graduate student, Michael Walker, reports that the magnetic material located within the ethmoid bone complex in the skulls of yellowfin tuna has been successfully extracted and analyzed. Walker and graduate student Anjanette Perry, Andrew Dizon of the NMFS La Jolla Laboratory, and J. Kirschvink of Princeton University have been conducting a search for magnetic crystals in migratory Pacific tunas and green turtles.

Magnetically clean dissections of 35 yellowfin tuna skulls were made and the tissue from within the ethmoid bones removed. The collected tissue was ground with a teflon pestle, the fats were extracted with ether, and the remaining tissue digested in 5.25 percent sodium hypochlorite solution (household bleach). After centrifuging and washing, a colorless residue remained. When a strong magnet was brought up to the side of the test tube, small black particles aggregated near the magnet and followed it as it was moved.

An X-ray diffraction pattern obtained from one of these particles showed that it contained magnetite, the material believed to be the likely basis for the magnetic sense in tuna. This mineralogical study of the magnetic material in the heads of tuna confirms previous magnetometry studies which indicated that the material could be magnetite. (Source: *Tuna Newsletter*, 77:2.)

A Computer Assisted Fishery Export Service

Companies wanting to increase export sales may contact the National Marine Fisheries Service (NMFS) regarding a program provided to the U.S. seafood industry to help increase exports of fishery products. By contacting NMFS, a company's name and the products it has to export will be added to a data system entitled "Computer Assisted System for Export of Seafood" (CASES).

When NMFS receives foreign sales inquiries for seafood, these inquiries are matched with the data in the system, and if a firm can supply the needs of the

buyer, the sales opportunity will be sent to it. For more information about this service, please write Kenneth T. Ellington, National Marine Fisheries Service, F/UD1, Washington, DC 20235 or telephone (202) 634-7451.

New Policy Addresses Seizure of Illegal Fish

NOAA has revised its policy of seizing and seeking forfeiture of fish it believes were taken or retained in violation of the Magnuson Fishery Conservation and Management Act (MFCMA). The revised policy allows National Marine Fisheries Service special agents to seize a vessel's entire catch if the vessel has committed previous violations of the MFCMA, or if the violation in question is especially serious (regardless of previous violation history), or if the violation in question involves multiple counts.

Effective enforcement of the MFCMA, and protection of fishery resources, requires this more severe response to flagrant and repeated violations. Therefore, this new policy makes clear that in cases involving serious violations of federal regulations, NOAA will seize and seek forfeiture of a vessel's entire catch.

NOAA will consider seizure and forfeiture of the vessel in addition to its catch in serious cases where lesser penalties have not been, or would not be successful deterrents. For additional information, contact Marguerite Matera, Staff Attorney, Office of General Counsel, NOAA (617) 281-3600.

Transport Program Reduces Salmonid Smolt Losses at Hydroelectric Dams

Transportation of steelhead trout, *Salmo gairdneri,* and chinook salmon, *Oncorhynchus tshawytscha,* smolts to bypass eight hydroelectric dams on the Columbia and Snake Rivers in the Pacific Northwest (Fig. 1) has increased the number of juvenile fish that survive the downstream run. The number of adults that return to spawn may increase to predam levels for some species, reports Donn Park of the Coastal Zone and Estuarine Studies Division of the NMFS Northwest and Alaska Fisheries Center (NWAFC), Seattle, Wash.

Smolts transported around the dams are spared the perils that have been raising their mortality rates steadily since the dams were built. Mortalities rose dangerously after the last four dams were completed: John Day Dam in 1968, Lower Monumental Dam in 1969, Little Goose Dam in 1970, and Lower Granite Dam in 1975 (Fig. 1).

Downstream migrant salmonids passing a dam ordinarily follow one of two paths. If river flow is low and no water spills over the dam, the fish are forced to pass through the turbines. If they aren't killed directly in the turbine, those emerging face a concentrated predator fish population waiting to attack stunned and injured smolts.

The smolts may follow a second path when the river flow is high. If water is spilling over the dam, fish that don't go through turbines can pass in the spilling water. Although passage over the spill is a safer route than passage through turbines, even this route can be dangerous. During high spill, the water picks up air as it falls and, at some dams, higher levels of dissolved gases than fish can tolerate may result. Smolts can die from gas-bubble disease, a condition caused by excessive absorption of gases (primarily nitrogen) through the gills. As more turbines are added to existing dams, fewer fish pass over the dams with spilling water: Most pass through the turbines.

The smolt transportation program reroutes the smolts that would normally go through the turbines. The system can be divided into two parts.

First, fingerling bypasses can be built into each dam. As seaward-bound smolts enter the turbine intake, the majority are intercepted by a screen that directs them into a protected area called the turbine gatewell. An opening in the gatewell leads to a bypass channel through which the smolts pass to the tailrace on the other side of the dam. This bypass system passes 50-70 percent of the smolts, sparing them from the dangers at that particular dam.

If they faced only one dam, the bypass

Figure 1.—Dams on Snake and Columbia Rivers involved in the fish transportation program.

system would be enough to maintain satisfactory runs. At each successive dam, however, the smolts that aren't rerouted through the bypass system suffer a mortality of 15-20 percent. Smolt mortalities from repeated passages through the turbines add up and the surviving population is significantly reduced.

The second part of the transportation program prevents repeated run reductions at each dam. Instead of releasing smolts from the tailrace directly into the river, researchers truck (Fig. 2) or barge (Fig. 3) them from upriver dams to a release site below the nearest dam to the estuary, Bonneville Dam. Although some smolt mortality is associated with trucking and barging, the number lost in a single transporting is far less than the number that would be lost if the smolts had to pass through each dam's danger areas.

Steelhead trout have shown the best adult return figures of the transported species. During years when the river flow is low, the returns from transported smolts far outnumber those from nontransported smolts. For example, in a 1980 NOAA Technical Memorandum, Donn park wrote than in 1973, only 3.5 percent of the seaward migrants were transported, but they provided 40 percent of the adult returns from that year. During years when the river level allows some water to spill over the dams, the increased adult returns from transported steelhead trout aren't as spectacular, but they still outnumber returns from those not transported.

Chinook salmon returns increased appreciably during the early years of transporting but the return levels diminished during later years. While total numbers of returns to the river have been lower than expected, the returns of adults from previously barged and trucked smolts have been consistently higher than returns from nontransported smolts. For example, during 1978, approximately six chinook salmon adults trucked or barged as smolts returned for every return from nontransported controls. Researchers suspect that early-ocean mortality may be decreasing the total adult returns—without transportation, total adult returns could be even lower.

Transportation successes from Ice Harbor, McNary, Lower Granite, and Little Goose Dams have encouraged researchers to expand the program. Each year equipment is upgraded and added so that more smolts are transported with the least possible stress. Transport programs have been expanded to include coho, *O. kisutch;* sockeye, *O. nerka;* and summer and fall chinook salmon as well as the steelhead trout and spring chinook salmon. The trucking and barging of smolts around dangerous dams is now joining such programs as hatchery and fingerling bypass systems. They are all essential for preserving the Pacific Northwest's salmonid resources.
Mary Lee Sibley-Armour, NWAFC

Figure 2.—Truck used to transport Pacific salmon smolts from upriver dams to a safe release site below Bonneville Dam.

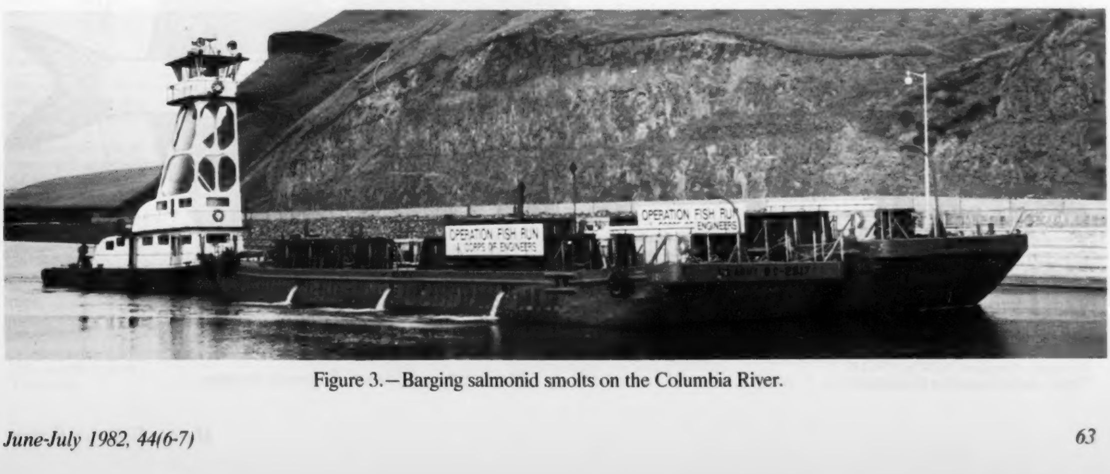


Figure 3.—Barging salmonid smolts on the Columbia River.

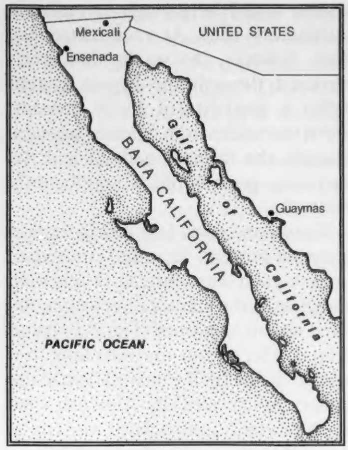
The Mexican Fishery for Northern Anchovy, *Engraulis mordax*

The northern anchovy, *Engraulis mordax*, is the most abundant species found in the California Current which dominates the coastal waters off the Baja Peninsula in Mexico and off Southern California in the United States. Until recently, the species was relatively unutilized by either Mexican or U.S. fishermen.

In the early 1970's, however, Mexico initiated a massive fishing effort for this species which has now become the largest single component of the country's fisheries catch. The increased anchovy catch has enabled the current Mexican Administration to claim that the massive $1.4 billion fisheries development program has been a great success. Some observers, however, are concerned that anchovy stocks may not be able to support the intensive fishing effort over a sustained period.

Catch

Almost all of Mexico's anchovy catch is taken off the Pacific Coast of the Baja Peninsula (see map). About 80 percent of that catch is landed in Ensenada. The fishery was originally conducted within 5 miles, but recent reports from the port of Ensenada indicate that the fishermen have now moved further offshore. The highly seasonal catch is mostly taken between May and December (Table 1) when Mexico's entire anchovy/sardine fleet is based in Ensenada. During the rest of the year, many of these vessels are based in Guaymas, where they are deployed for sardine fishing in the Gulf of California.

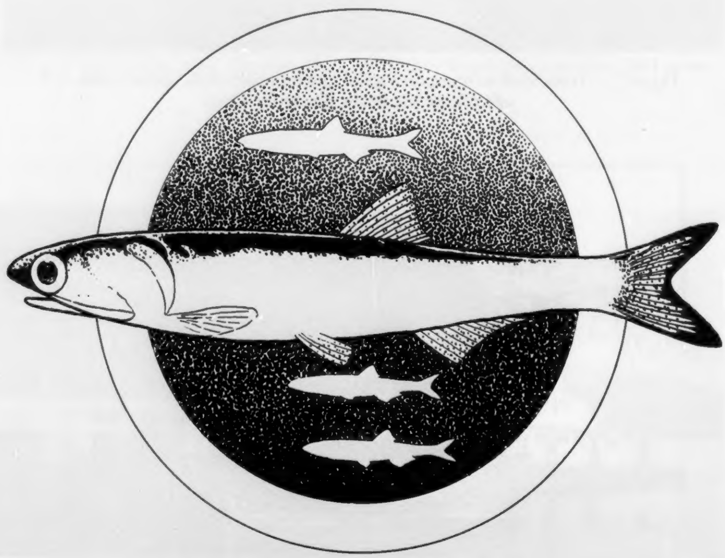


Mexican fishermen have sharply increased their anchovy catch in recent

Table 1.—Mexico's anchovy catch by month and type of processing, 1979, in 1,000 t[1].

Month	Utilization: Edible	Fish meal	Total[2]
January	Negl.	1.1	1.1
February	Negl.	3.1	3.1
March	0.1	0.7	0.8
April	Negl.	7.1	7.1
May	0.2	35.8	36.0
June	0.1	21.7	21.8
July	0.4	29.6	30.1
August	0.1	16.2	16.3
September	0.4	10.7	11.1
October	0.6	22.3	22.9
November	1.2	25.7	26.9
December	0.3	23.0	23.3
Total[2]	3.4	197.0	200.4

[1]Discrepancy with Table 2 is unexplained.
Source: Departamento de Pesca, "*Anuario Estadistico Pesquero*, 1979." p. 134-135.
[2]Totals may not agree due to rounding.



The northern anchovy, *Engraulis mordax*.

years. Preliminary statistics suggest that the catch totaled nearly 340,000 metric tons (t) in 1980, a 20 percent increase over the 250,000 t taken in 1979 (Table 2). Preliminary 1981 reports indicate that the 1981 catch will exceed the 1980 catch, but much will depend on the November-December results, which were not yet available. Mexican officials eventually hope to increase the annual catch to 500,000 t.

Fish Meal Production

The development of the Baja anchovy fishery has enabled Mexico to increase its fish meal production to about 80,000 t (Table 3). The anchovy catch is being used primarily for reduction to fish meal. Fish meal is used as a dietary supplement by Mexico's important poultry and livestock industry. Before 1976, Mexico imported most of its fish meal. The increased domestic production based on the anchovy has enabled the country to keep imports below 30,000 t.[1]

Government officials eventually hope to use the anchovy as an important part of its program to increase domestic food production. The Departamento de Pesca (DEPES) wants anchovies to be used to produce edible products and has met with fish meal companies to plan for their reduced use for fish meal. Instead, DEPES wants the fish meal plants to use offal from canneries and freezing plants and species which cannot be used to produce edible products.[2] It is likely to be several years, however, before such a shift is actually implemented. As part of its fish meal policy, DEPES had planned to restrict the construction of additional fish meal plants. Unconfirmed reports from Mexico, however, suggest that DEPES may have reevaluated its anchovy policy, at least for the immediate future, and now plans to authorize the construction of additional fish meal plants. The Bank of Mexico has been considering loans to finance the construction of additional fish meal plants in 1982.

Table 2.—Mexico's North Pacific Anchovy catch, 1975-80[1].

Year	Quantity (1,000 t)	Year	Quantity (1,000 t)
1975	59.6	1978	180.1
1976	79.4	1979	249.6
1977	178.8	1980	339.0

[1]The Baja California Norte catch through June 1981 was 95,500 t. Sources: FAO "Yearbook of Fishery Statistics," 1979 (1975-79 data) and NMFS Southeast Fisheries Center (1980 data).

Table 3.—Mexico's fish meal production, imports, exports, and consumption, 1975-81, in 1,000 t[1].

Year	Production	Imports	Exports	Total consumption
1975	35.0	47.5	Negl.	82.5
1976	[2]47.0	30.6	Negl.	77.6
1977	53.7	14.3	Negl.	68.0
1978	59.4	24.0	Negl.	83.4
1979	75.2	[3]42.1	Negl.	117.3
1980	[2,4]79.0	[2]20.0	Negl.	[2]99.0
1981[5]	[6]80.0	[6]25.0	Negl.	[2]105.0

[1]Sources: FAO *"Yearbook of Fishery Statistics,"* 1979 (1975-79 import data) and *Oil World,* various issues (1975-81 production data and 1980-81 import data).
[2]Estimate.
[3]Different sources on Mexican fish meal are in rough agreement, with the exception of 1979. The publication *Oil World* estimated that only 26,000 t was imported that year while FAO and the International Association of Fish Meal Manufacturers reported that 42,100 t was imported.
[4]*Oil World* estimate may be low. Based on the 1979 anchovy catch, fish meal production could have reached 90,000 t.
[5]Projection based on *Oil World* January to September 1981 forecast of 60,000 t produced and 14,000 t imported, compared with 59,000 t produced and 9,000 t imported from January to September 1980. Again the *Oil World* projection may be low based on the projected 1981 anchovy catch.
[6]Projection.

Companies

Several Mexican companies, based in Ensenada, fish for anchovies. In 1979, there were eight fish meal plants in the Ensenada area, less than 10 percent of the country's 86 fish meal plants. Those eight plants, however, produced more than half of Mexico's entire fish meal production in that year.

The most important fish meal company is Pesquera Zapata, S.A.,[3] a Mexican-United States joint venture formed in 1974. Pesquera Zapata catches and reduces about 80 percent of the anchovies landed in Ensenada. The company began operations in 1976 with six U.S.-built 33 m long purse seiners and later added additional Mexican-built purse seiners. In 1980, Pesquera Zapata purchased three new seiners from a Norwegian shipyard. These new vessels will increase the company's fleet to 13 vessels.

At the height of the season, the company employs 450-500 workers processing anchovies and sardines into fish meal and oil. It operates a totally integrated plant with the most modern facilities in Mexico. It is the only fish meal plant in Mexico, for example, with offshore landing facilities. The catch is fed into a 36 cm pipe which runs underwater to the plant. The company claims that air and water pollution is thus avoided, although some local observers believe that the system has not entirely solved the pollution problem. Unconfirmed reports from Ensenada suggest that because of various problems with the pump, much of the catch during 1981 was landed manually in Ensenada and trucked to the Zapata plant.

Once in the plant, the fish are pressed, crushed, and cooked; the product is then dried and the meal milled while the liquid is treated and separated into various components. Continuous analysis of the catch is conducted at the plant to study the size, age, and sex of fish. The plant has the capacity to produce 100 t of fish meal per hour. The plant's entire production is marketed domestically. It is shipped to the Mexican rail center of Mexicali and from there it is distributed throughout Mexico.

Mexico's state-owned company, Industries Pesqueras Paraestatales del Noroeste (IPPN), is also interested in processing anchovies. In 1980, however, IPPN only canned about 5,000 t of anchovies at its Ensenada plant. The company hopes to increase substantially its anchovy utilization in the future. IPPN is primarily responsible for supplying the domestic market with edible fishery products.

IPPN not only hopes to can more anchovies, but is also planning to use anchovies and other species such as hake to produce fish protein concentrate (FPC). IPPN has ordered an FPC plant from a company in the United States

[1]Mexican statistics report fish meal imports of 42,000 t in 1979. Some observers believe that official statistics are in error and that actual imports did not exceed more than 26,000 tons.
[2]Details on Mexican Government plans for the fish meal industry can be obtained by requesting "Mexican Fish Meal Industry" (IFR-81/111) from your local NMFS Statistics and Market News office.
[3]Mention of trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

and hopes to begin production in 1983. The recent installation of an unloading pump has increased the plant's unloading capacity to 80 t of anchovies or sardines per hour. More importantly, the pump has improved the quality of the unloaded fish. Before the pump was installed, 40 percent or more of the landings were unfit for processing into edible products. IPPN officials now claim that almost all of the fish landed with the new pump can be canned.

DEPES announced plans in September 1981 for the construction of a new $3.2 million cannery in Ensenada. It is not known at this time who will build the cannery, but it will probably be operated by IPPN. The cannery will eventually be able to process 10,000 t of anchovies annually. DEPES estimated that it will take about 2 years to build the plant.

Prospects

Stock assessment surveys conducted by the National Marine Fisheries Service (NMFS) suggest that in an average year, about 70 percent of the anchovy stock is found in the U.S. 200-mile Fisheries Conservation and Management Zone and about 30 percent within the 200-mile Exclusive Economic Zone (EEZ) claimed by Mexico. U.S. anchovy fishermen, however, are strictly regulated. The U.S. anchovy catch in 1980, for example, was only about 50,000 tons. U.S. and California officials, as a result, are becoming increasingly concerned by the rapidly increasing Mexican catch.

Many U.S. officials are convinced that anchovy stocks can probably not tolerate a sustained annual catch in excess of 500,000 t, which is the Mexican goal. U.S. officials maintain that anchovy stocks, like the stocks of other small pelagic species, are subject to extreme annual fluctuations. Estimates for 1980, for example, suggest an anchovy biomass of 2.8 million t, which probably could have supported a 0.5 million t catch in that year. As recently as 1978, however, a biomass of only 1.3 million t was estimated by the NMFS. A Mexican catch approaching the 0.5 million t level during that year could have had a disastrous impact on the anchovy stock. U.S. officials point out that fisheries, much larger than the northern anchovy fishery, have been decimated by combinations of adverse environmental conditions and overfishing.

Most Mexican officials and private consultants, however, are convinced that the anchovy stock can withstand the increasing fishing effort and cite FAO studies suggesting a possible maximum sustainable yield of from 1.5 to 2.0 million t. Some Mexicans are concerned, however, about the future of the fishery. Especially disturbing have been reports from the fishermen who say that they have had to search for anchovy further and further off the coast, and that the range of the stock appears to be contracting. In addition, an increasing percentage of juvenile anchovy was taken during 1981. Some observers believe that these developments, especially the increasing proportion of juveniles, is an indication that the intensive Mexican effort on anchovy is adversely affecting the stocks. (Source: IFR-82/7.)

Canada-EC Sign 6-Year Fisheries Agreement

The Canadian Government and the European Community (EC) have signed a 6-year fisheries agreement. Drafted and initialed by both countries in November 1980, it was finally signed by Canadian and European Community officials in Brussels on 30 December 1981. The agreement was originally to have covered the 6-year period from 1981 to 1986; Canada and the EC, however, held up implementation for more than 1 year. Consequently, it will be in force from 1982 through 1986, although negotiations for a possible 1-year extension are being considered.

The final agreement, which does not differ substantially from the 1980 draft, guarantees EC vessels fishing rights for cod and squid taken from Canadian-claimed waters. The cod allocation to EC fishermen will be 16,000 metric tons (t) annually through 1986; the squid allocation will be 7,000 t per year (Table 1). In exchange, the Canadians will be

Table 1.—Canada's annual catch quotas allocated to the European Economic Community, by species and area, 1982-86.

Species	NAFO zones[1]	Quantity (t)
Cod	2J, 3K, and 3L	9,500
Cod	2G and 2H	6,500
Total		16,000
Squid	3 and 4	7,000
Grand total	2, 3, and 4	23,000

[1]Northwest Atlantic Fisheries Organization zones.

Table 2.—European Community annual import quotas and reduced import duties for Canadian fishery exports, 1 January 1982 to 31 December 1986.

	Duty (%)		Quantity				
Commodity	EC Import	Reduced	1982	1983	1984	1985	1986
Frozen							
Cod whole[1]	13.9	[2]3.7	5,000	6,000	6,000	6,000	6,000
Redfish, whole	15.0	[2]4.0	8,000	8,000	9,000	9,000	9,000
Cod fillets[1]	15.0	[2]6.0	10,000	11,000	12,000	13,000	15,000
Total, frozen			23,000	25,000	27,000	28,000	30,000
Salted							
Cod fillets[1]	20.0	–	NA[3]	NA	2,500	3,500	4,000
Cod whole[1]	13.0	–	NA	NA	4,000	5,000	6,000
Pickled herring	20.0	10.0	4,000	4,500	6,000	6,500	7,000
Total, salted			NA	NA	39,000	43,000	47,000
Grand total			NA	NA	66,000	71,000	77,000

[1]The EC requires a certificate of Canadian origin for all North Atlantic cod, *Gadus morhua*, imports.
[2]The reduced tariffs apply only to Canadian fishery exports that will be processed in the EC. Prior minor handling such as cleaning, sorting, packing, etc., will not qualify Canadian exports for the reduced duty. The reduction is also not allowed if the processing is to be carried out at the retail level. In addition, only fishery products for human consumption qualify.
[3]NA = Not available.

allowed to export specific quantities of fish to the EC at lower than regular tariffs; this quantity will be increased annually (Table 2). The Canadians will export partially processed products which will be produced in final form by European companies.

Background

Canada is aggressively attempting to develop its fishing industry, primarily by expanding export markets for its increasing catch. Much progress has been made in recent years and, in 1980, Canada was the world's leading exporter of fishery products (US$1 billion). As part of the Government's fisheries development policy, Canada has tied catch allocations in its 200-mile fishing zone to foreign cooperation in lowering tariff and nontariff barriers on Canadian fishery exports. Several EC countries have been interested in access to Canadian-claimed fishery resources because restrictions by other coastal countries have closed many traditional fishing grounds to distant-water fleets.

The Federal Republic of Germany (FRG) is the most important of these. In 1980, the FRG's 2,000 deep-sea fishermen caught 175,000 t of fish, of which 60,000 t was cod. Nearly 15,000 t of the cod catch (about a quarter of the total) was obtained from Canadian-claimed waters and it is evident that the modern and profitable German distant-water fleet needs access to Canadian-claimed waters. Furthermore, the FRG distant-water fleet operates from two principal German ports, Cuxhaven and Bremerhaven, both of which have suffered severe economic problems, especially in the steel and auto industries. The FRG Government consequently feels it desirable to support the distant-water fishing industry (which employs 15,000 fish processors in addition to the 2,000 fishermen). The FRG, in its role as the primary economic power of the EC, was one of the major proponents of a fisheries agreement with Canada.

Agreement Negotiated

With these mutual benefits in mind, a fisheries agreement was negotiated by the EC and Canada during 1980 and initialed in November of that year. It immediately became a point of controversy within the fishing industries of both Canada and the EC. Disagreement about the benefits and drawbacks of the proposed treaty became a source of continual debate in both the Canadian and the EC fishing communities for more than a year.

Canadian Objections

Canadian Atlantic coast fishermen and processors immediately criticized the draft agreement. The Canadians had two principal objections: many felt that it would not be in Canada's interest to give up part of its catch to the Europeans in exchange for reduced tariffs on Canadian fish, which they believed the Europeans would probably buy anyway to support their fish processing industry. This proved not to be the case, however, and a weakening market for Canadian fishery exports in 1981 changed the minds of many Canadians, especially in the processing sector.

Secondly, many Canadians also objected to a clause permitting Greenland fishermen to catch salmon along Greenland's western coast.[1] A significant percentage of the salmon fished by Greenland fishermen spawn in Canadian rivers. The agreement allotted EC fishermen a quota of 1,190 t of salmon west of long. 44° W, but both sides agreed the quota might be increased slightly if the season were begun later and if the fishermen used a larger mesh size. The EC subsequently set a later starting date for the season and raised the salmon catch quota to 1,270 t. Canada objected that the EC failed to implement the mesh size change and that the quota was too high. The higher catch limit and the dispute over the mesh size caused considerable opposition to the agreement with the EC in Canada.

European Objections

Opposition to the proposed agreement within the EC came mainly from the United Kingdom. British fishermen would not benefit from the agreement because Britain no longer has a distant-water fleet. Much of the cheaper Canadian fishery exports would be sold on the already depressed British markets and compete with the catch of British fishermen. The U.K. Government withheld approval of the agreement to press its demand within the EC Fisheries Commission for a Common Fisheries Policy (CFP). U.K. fishermen, especially the Scots, have protested the importation of low-priced fish for their market. The CFP has long been a special problem for the United Kingdom whose fishermen claim that, because two-thirds of the EC fisheries catch is taken in British coastal waters, they should receive special rights within the EC-claimed 200-mile zone.

Most other EC member states have rejected these demands as a violation of the basic right of all EC member states to equal access to EC-claimed fishery resources. Successive British Governments have used EC fishery negotiations with non-EC members to press the U.K. views of the CFP. As a result, in February 1981, the British repeated their longstanding position (at a meeting of EC foreign ministers in Brussels) that there could be no agreements with outside countries until the EC member-states had settled their dispute over the Community's internal fisheries policy.

EC Approves Treaty

The United Kingdom finally accepted the Canada-EC fisheries agreement after assurances were given guaranteeing the protection of EC markets from an excess of low-priced foreign fishery imports. Under this arrangement, when fish are imported into an EC member-state at prices below the established reference price,[2] that state will notify the EC Commission which must take corrective action within 3 days. British fishermen had complained for some time that the EC reference price system was

[1]Greenland is part of the Danish realm and consequently is included as an EC member state in EC fisheries agreements with nonmember countries. Greenland's catch quotas are set by the EC.

[2]Reference prices are minimum import prices established by the EC to protect domestic fishermen from foreign competition.

too slow and cumbersome to protect them from cheap foreign imports. The new assurance of swift EC action was accepted by the British Government, although some fishermen were still skeptical that the problem had been solved. With British acquiescence, the EC finally approved the agreement on 29 September 1981.

Canada Approves Treaty

After the EC approved the agreement, the Canadian Government felt that further study was needed before making the agreement final. The full impact of the new reference price system adopted by the EC was of particular concern to the Canadians. They believed that a thorough examination of this policy was required to verify that Canadian fishery products, especially frozen cod filets, would not be penalized. After a reexamination of the agreement, the EC reference price system, and the fishing industry's attitude toward the agreement, the Canadian Government finally decided to approve the treaty.

Agreement Signed

The formal signing of the agreement by Canadian and EC authorities took place in Brussels on 30 December 1981. The EC members were especially interested in enacting the agreement before the end of the year so that EC fishermen could begin operations in Canadian waters as soon as possible in 1982.

Remaining Problems Resolved

Canadian and EC officials remained in Brussels after 30 December 1981 to discuss a few remaining "minor" details concerning the implementation of the agreement. The Canadians were, however, not satisfied with the outcome of these informal talks and were concerned over which EC-member countries would import what quantities of Canadian fishery products. Canadian and EC officials subsequently met on 25 January 1982 and resolved their differences.

The NMFS Foreign Fisheries Analysis Division has learned that the Canadians have begun to issue permits to EC fishing vessels. Still unresolved, however, is a possible 1-year extension of the agreement to 31 December 1987. (Source: IFR-82/25.)

Canada Okays Over-Side Sales to Foreign Firms

The Canadian Government has described two new over-the-side, direct sales contracts with foreign companies. Fishermen from the Maritime provinces (Nova Scotia, Newfoundland, and Prince Edward Island) and Quebec will be permitted to sell mackerel and river herring (gaspereau) directly to foreign buyers.

One contract is between the Maritime Fishermen's Union and the Joint Trawlers (Canada) Company[1] of St. Johns, Newfoundland, a subsidiary of Joint Trawlers of Helsinglorg, Sweden. The second contract is between the Eastern Fishermen's Federation, J. Marr Seafoods company of Hull, United Kingdom, and the AMFAL Group of Dartmouth, Nova Scotia.

The first of seven foreign freezer vessels was scheduled to arrive on 15 May 1982 to begin receiving the mackerel catch off eastern Nova Scotia. Another vessel was to begin receiving river herring on 19 May at Chatham, New Brunswick.

Foreign vessels are required to remain at their purchasing stations for a specified number of days. If the vessel arrives late, or leaves early, and does not fulfill its minimum number of purchasing days, the foreign partner would lose a significant portion of the catch allocation to which it would have been entitled. In the past, some Canadian fishermen did not have enough time to reach the foreign purchasing vessels. The new minimum purchasing days rule will give Canadian vessels more time to sell their catch.

The price Canadian fishermen will receive was established at 13 cents/pound (28.7 cents/kg) for mackerel and 8.5 cents/pound (18.8 cents/kg) for alewives.

Canadian Department of Fisheries and Oceans officials are monitoring the implementation of the two over-the-side sales agreements. If a partner to the contract encounters difficulties, the Minister of Fisheries has reserved the right to intervene to resolve the problem.

The contracts will give the European partners direct access to a limited amount of offshore species which have not been traditionally fished by Canadians and in which Canadian fishermen have shown little interest. Foreign vessels deployed under the contracts will be subject to the Canadian access and fishing fees for foreign flag vessels.

Sales of fish by Canadian fishermen directly to foreign buyers have been authorized by the Government of Canada intermittently since 1976. The program has provided an opportunity for inshore Canadian fishermen to sell that portion of their catch for which no Canadian market exists at economically acceptable returns to fishermen. Total Atlantic coast over-the-side sales in 1981 represented less than one percent of total fishery landings in Atlantic provinces. (Source: Department of Fisheries and Oceans.)

[1]Mention of trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

Canadian Scallop Catch, and Culture Potential

The Ministry of the Environment of the Province of British Columbia has issued a report on the potential for scallop mariculture on the Canadian Pacific coast. The report concludes that while the technology is available, the economic feasibility and the availability of foreign and domestic markets is by no means sure and that more study is needed.

During January-August 1981, Canadian fishermen landed 60,600 metric tons (t) of scallops (round weight) or 29 percent more than during the comparable period in 1980 when 47,000 t were landed. The value of the 1981 catch was about $45 million. Canada exported 7,400 t of scallops (product weight) worth $73.5 million during January-September 1981 according to the latest Canadian statistics. During the same 9 months of 1981, scallop exports were valued at $52.2 million, 40 percent less than in 1981. Virtually all Canadian scallop exports went to the United States in 1981.

Marine Conferences Scheduled for Fall

Several marine fisheries conferences and symposia have been scheduled later this year. Among them are the following:

The 5th annual International Seafood Conference, a widely recognized forum for industry leaders worldwide, will convene in Tokyo, Japan, 25-28 October. This is the first time the conference will be held in Asia and the program will emphasize topics relating to the fisheries of the Pacific and their importance in international seafood production and marketing. For further information, contact the International Seafood Conference, 1101 Connecticut Ave., N.W., Suite 705, Washington, DC 20036.

The 27th annual Atlantic Fisheries Technological Conference will be held 20-23 September in Portland, Maine, and will cover a wide range of topics of interest to industry, academia, and government technologists, researchers, etc. Sessions will address 1) the fisheries of Maine and New England, 2) organoleptic testing and methodology, 3) quality control and improvement, 4) New England Sea Grant programs, and 5) other topics of general interest. For further information, contact Anne T. Craig, F/UD2, NMFS, NOAA, 3300 Whitehaven St., N.W., Washington, DC 20235.

Duke University Marine Laboratory and Fundacao Universidade do Rio Grande have announced an international symposium on "Utilization of Coastal Ecosystems: Planning, Pollution, and Productivity" to be held 22-27 November at the Brazilian university. The program will include both invited speakers and contributed papers. For further information, contact the Local Committee, International Symposium on Utilization of Coastal Ecosystems, Fundacao Universidade do Rio Grande, P.O. Box 474, Rio Grande/RS—96.200—Brazil.

And, the Mid-Atlantic Fisheries Development Foundation will hold its annual program planning session in Rehoboth Beach, Delaware on 17-18 September, followed by a Board of Trustees meeting to formulate development activities for 1983-84. Further information is available from William F. Carroll, Project Director, Mid-Atlantic Fisheries Development Foundation, Suite 600, 2200 Somerville Road, Annapolis, MD 21401.

Label Clearance Program Reinstated

In reponse to popular demand, the USDA label clearance program, which was suspended November 1981, has been restored. For those who may not be familiar with this program, it can help you find out if your product will be admitted into a given country. Just send the label(s) of your product(s), indicating ingredients to the Foreign Agricultural Service (FAS). A form with complete instructions is available for this purpose. A $25.00 fee is charged per label (or carton or lithographed container) per country.

The label(s) will be forwarded by FAS to the Agricultural Counselor or Attache for clearance by the foreign government. You will be informed whether or not your product can be admitted as is or if approval might be given if certain changes were made. Changes required tives, food colorings, language, metric requirements, or date coding.

For copies of the label clearance forms, contact the Export Promotion Division, Foreign Agricultural Service, Washington, DC 20250; telephone (202) 447-7103. All labels should be sent to this address. For technical questions regarding requirements in various countries, contact Thomas O'Connell, Trade Policy, Planning, and Analysis Division, FAS, U.S. Department of Agriculture, Washington, DC 20250; telephone (202) 382-1318.

Foreign Violations of U.S. Fish Rules Noted

In the period from 1 January 1982 to 22 April 1982, the U.S. Coast Guard conducted 148 boardings of foreign fishing vessels in the Atlantic area north of Cape Fear, N.C., and in the Gulf of Maine to enforce the Magnuson Fishery Conservation Act and the Atlantic Tunas Act. In this 112-day period, Spanish vessels were boarded 102 times and received 37 written warnings and 53 violations, while Italian vessels were boarded 34 times and received 11 written warnings. Japanese vessels were boarded 11 times and a Bulgarian vessel was boarded once, but neither country received warning or violation citations. A violation can result in a civil penalty of up to $25,000 for each offense. The amount of the penalty or sanction is assessed by the NMFS upon review of the seriousness of each case. (Source: U.S. Coast Guard.)

Early Joint Venture Pollock Catch up 340%

As of 27 March 1982, U.S. fishermen had landed over 57,000 t of Alaska pollock in joint venture fisheries in the central Gulf of Alaska. This represents a 340 percent increase over last year's joint venture harvest in the central Gulf of 16,836 t. The fishery is expected to take at least another 10,000 t before the schools of pollock in Shelikof Strait disperse and fishing activities cease.

The Council had allocated only 7,940 t of pollock for 1982 joint ventures in the Gulf of Alaska, with 19,040 t in reserve for unanticipated domestic catches and about 40,000 t of pollock designated for foreign fisheries which had not yet been released. (Source: North Pacific Fishery Management Council, Anchorage, Alaska.)

New NMFS Scientific Reports Published

The publications listed below may be available from either the Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402, or from the National Technical Information Service, U.S. Department of Commerce, Springfield, VA 22151. Writing to the agency prior to ordering is advisable to determine availability and price, where appropriate (prices may change and prepayment is required).

NOAA Technical Report NMFS Circular 442. Sindermann, Carl J. (editor). **"Proceedings of the Sixth U.S.-Japan Meeting on Aquaculture, Santa Barbara, California, August 27-28, 1977."** March 1982, iii + 66 p. (5 papers.)

NOAA Technical Report NMFS Circular 443. Palko, Barbara Jayne, Grant L. Beardsley, and William J. Richards. **"Synopsis of the biological data on dolphinfishes, *Coryphaena hippurus* Linnaeus and *Coryphaena equiselis* Linnaeus."** April 1982 iv + 28 p., 15 figs., 10 tables.

(No abstract.)

NOAA Technical Report NMFS SSRF-752. Lux, F. E., and F. E. Nichy. **"Movements of tagged summer flounder, *Paralichthys dentatus*, off southern New England."** December 1981. 16 p.

ABSTRACT

A total of 2,839 summer flounder were tagged on outer continental shelf and coastal grounds off southern New England in 1961-62. Tag recaptures showed the migration to offshore grounds in fall and winter and to inshore areas in spring and summer. Recaptures from coastal grounds were recorded from northern New Jersey to south of Cape Cod; those from outer shelf grounds were from Baltimore Canyon on the southwest to Veatch Canyon on the northeast. The overall tag return rate was 21.2 percent; however, the returns from inshore tagging (44.5 percent) were much higher than those from offshore releases (8.4 percent), suggesting that tagging mortality was higher offshore.

NOAA Technical Report NMFS SSRF-753. Low, R. A., Jr., and S. B. Mathews. **"Factors influencing ocean catches of salmon, *Oncorhynchus* spp.,**

Progress in Fisheries Technology, Utilization

"Nahrung aus dem Meer," subtitled in English "Food from the Sea," and published by Springer-Verlag, Berlin, West Germany, is a collection of interesting and useful papers from an international symposium of the same title held in Bremerhaven in October 1980. Editor is Horst Noelle.

Nine of the nineteen papers are in English; the rest are in German. In the English-language papers, Z. S. Karnicki of FAO reviews the effects of EEZ's on world fish production, R. Young of Scotland reviews their experiences in net-pen rearing of Atlantic salmon, and mussel protein values, their variation, and studies on a mussel protein concentrate are reported by G. Varela of Spain.

H. Kunachowicz of Poland details the nutritive values of krill and its possible role in human nutrition. Problems in animal feeding studies with krill products are related and further research is recommended before introducing krill into the human diet.

Constituents of commercial and industrially important algae are discussed by W. Becker of Germany. Likewise, the use of seaweeds in human food and medicine in Japan is reviewed by S. Matsuzaki and K. Iwamura. H. M. Sinclair reviews the possible importance of a fish diet in preventing several chronic degenerative diseases, stressing that much further research is needed. Contaminants (i.e., mercury, PCB's, etc.) in fish and their monitoring in the United Kingdom are briefly described by A. W. Hubbard. J. J. Connell et al. examine potentially hazardous substances (PNAH, CP, CDD) in smoked fish products.

Papers in German review the limits of marine food production; fisheries and nutrition investigations; location, catching, and processing of krill; rat-krill feeding studies with particular reference to fluoride; underutilized species; fish in the human diet; fish nutrition, cardiovascular illness, and serum cholesterol; handling biological wastes, and toxic substances (PCB's, pesticides, heavy metals, etc.) in marine species.

The 260-page small-format (6½×9½") paperbound volume is available from the publisher at DM78 (about $37.20, subject to change).

Publication of **"Trends in Fish Utilization"** by J. J. Connell and R. Hardy, a Buckland Foundation book, has been announced by Fishing News Books Ltd., 1 Long Garden Walk, Farnham, Surrey, England. Much of the world's marine protein is not fully utilized and the authors, director and assistant director, respectively, of the Torry Research Station, drawing on their own research, discuss how these raw materials might be exploited more effectively by the United Kingdom.

Following a brief introduction, the authors review in chapter 2 a number of fishery resources either unused or un-

off Washington and Vancouver Island." January 1982. 12 p.

ABSTRACT

The relative influence of various factors on ocean fishing success was evaluated for pink, *Oncorhynchus gorbuscha*, chinook, *O. tshawytscha*, and coho, *O. kisutch*, salmon off Washington and Vancouver Island. In addition, an evaluation was made of the practicality of predictive models for ocean catch. For each species, predictive regression equations were developed and their reliability evaluated in terms of the average percentage error of predicted catches from actual catches.

Pink salmon catches were significantly correlated with indices of brood year abundance and the average individual weight of fish caught in terminal areas during the brood year. Average error of predicted catches ranged upward of ± 25 percent. Success for chinook salmon in year i was highly associated with Columbia River hatchery releases of fall brood year groups $i - 3$ and $i - 4$, Canadian purse seine catches of immature chinook salmon in Canadian area 20 during August of year $i - 1$, and troll catch per effort during the fall of year $i - 1$. Washington troll and sport catches of chinook salmon were also significantly correlated with the amount of nominal fishing effort. Coho salmon catches were significantly associated with level of fishing effort, indices of brood year abundance of Columbia River wild coho salmon, and Columbia River jack returns the preceding year. The average error of predicted annual troll coho salmon catches off the central Washington coast was ± 15 percent for 1966-75.

NOAA Technical Report NMFS SSRF-754. Smith, Gary B., and Richard G. Bakkala. **"Demersal fish resources of the eastern Bering Sea: Spring 1976."** March 1982, vii + 129 p.

ABSTRACT

During the spring of 1976, 683 otter trawl samples were collected within an area of 337,930 km^2 in the second of two baseline surveys designed to describe characteristics of Bering Sea demersal fish and shellfish populations.

Climatic conditions during the spring 1976 survey were anomalously cold, affecting both the pattern of trawl sampling and the apparent distributions of fish populations. During April and May, winter pack ice still covered 50-75 percent of the study area. Most demersal fish populations were distributed in deep water along the outer continental shelf where bottom water temperatures were warmest. At least two species populations showed extensive migrations.

A total of 78 fish species distributed among 22 families was recorded during the 1976 survey. The overall apparent mean density of demersal fish was 12.3 t/km^2 of which pleuronectids accounted for 67.8 percent, gadids 18.8 percent, and cottids 8.7 percent. Specific regions of highest fish densities were the outer continental shelf between St. George and Unimak Islands, directly west of St. Paul Island, and the central shelf area between Cape Newenham and Port Moller.

Comparisons between results of the first (August-October 1975) and second (April-June 1976) surveys were interpreted as representing seasonal extremes. During the survey of August-October 1975, apparently large-scale migratory movements had ended and the demersal fish populations were in late summer distributional patterns. Geographical ranges were generally broad and many species extended into Bristol Bay. During the survey of April-June 1976, demersal fish populations were apparently

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derused in the United Kingdom: Imported white fish (South African hakes, Alaska pollock, and Pacific cod), Atlantic mackerel, sprat, pilchards, crabs, blue whiting, scad, deepwater species (blue ling, grenadiers, black scabbard, and small sharks), dabs, mussels, squid, other shellfish (cockles, periwinkles, and whelks), Norway pout, sandeels, Argentines and silvery pout, Antarctic species (krill and various fishes), and recovered fish flesh.

Development of conventional fish products is reviewed in chapter 3—canning is believed to hold the most promise for U.K. expansion. Chapter 4 presents more recent developments and products: Laminated small-fillet blocks, kamaboko, moulded fillets, deboned flesh, fish protein concentrate, fish flour, etc. A final chapter discusses the problems in marketing fish and fishery products (pricing, marketing patterns, consumer attitudes, etc.). The authors also present estimates for potential U.K. increases in fishery utilization, providing the proper technologies and conditions are met. The 106-page paper bound, small-format (5½×8½") book costs £6 plus 60 p postage and is available from the publisher.

"Proceedings of the Sixth Annual Tropical and Subtropical Fisheries Technological Conference of the Americas," compiled by Ranzell Nickelson II, again presents a wide range of reports for the fishery technologist. Papers, edited by their respective authors, range from reviews of Guatemala's fisheries and factors influencing Asian shrimp quality to a Philippine fish market, the status of seafood technology in Venezuela, aquaculture in Mexico, shrimp mariculture, waste management rules in southern seafood industries, Louisiana's crawfish industry, and an evaluation of alligator meat.

Many of the papers contributed at the conference on 20-23 April 1981 dealt with shrimp: Marketability in South Carolina restaurants; effect of water, bisulfite, and hypochlorite rinses on microbial flora; rapid determination of decomposition; indole formation; differentiation of frozen-thawed and fresh shrimp; purification of phenoloxidase from Gulf shrimp; quality changes during iced storage of whole freshwater prawns; and more.

Other papers discuss seafood quality improvement, processing variables affecting color development in smoked mullet, optimization of drying conditions for stockfish produced from underutilized fish, quantitation of histamine in tuna using an enzyme affinity assay, development of an enzyme affinity assay for seafood products, Mississippi seafood processing economics, developing U.S. midwest markets for Gulf and south Atlantic seafoods, and more.

Copies of the proceedings, TAMU-SG-82-101, are available from the publisher, Marine Information Service, Sea Grant College Program, Texas A&M University, College Station, TX 77843, for $10 each.

sampled during a period of transition from late winter to early summer distributions. Compared to August-October 1975, species ranges were restricted more to deep water, although some populations were initiating migrations across the continental shelf.

NOAA Technical Report NMFS SSRF-755. Scarlett, Paul G. **"Annotated bibliography and subject index on the summer flounder, *Paralichthys dentatus*."** March 1982, iii + 12 p.

ABSTRACT

An annotated bibliography and subject index for 114 references are presented on the identity, distribution, life history, ecology, behavior, exploitation, and population dynamics of the summer flounder, *Paralichthys dentatus*.

NOAA Technical Report NMFS SSRF-756. McHugh, J. L., Marjorie W. Sumner, Paul J. Flagg, Douglas W. Lipton, and William J. Behrens. **"Annotated bibliography of the hard clam (*Mercenaria mercenaria*)."** March 1982, iii + 845 p.

(No abstract.)

The Pacific Halibut and Its Fishery

"The Pacific Halibut, The Resource and the Fishery" by F. Heward Bell, published by Alaska Northwest Publishing, Box 4-EEE, Anchorage, AK 99509, provides an excellent review of the biology, history, and economics of the species and the halibut industry. Bell, retired, was director of the International Pacific Halibut Commission.

Chapter 1 reviews the common and scientific names of the halibut and related species. The author believes that there is "little basis" for designating the Atlantic and Pacific halibut as separate species. Indian and commercial halibut fisheries are examined in chapter 2 while the sport fishery is discussed in chapter 15. Other chapters review fishing methods (dory fishing, longlining, netting), preservation methods, international agreements affecting halibut fisheries, the halibut commission and its research, and brief biographies of people involved in halibut fisheries, research, and management.

Likewise, halibut ports and landings are reviewed, as is the origin of halibut catches, the halibut industry and its economics, incidentally caught halibut, halibut marketing, etc. An "overview" chapter gives brief data on significant events and discoveries in the Pacific halibut fisheries.

The large format ($8\frac{1}{2} \times 11''$) volume has 267 pages, is indexed, provides a bibliography, and is well illustrated with over 300 photographs. Historians, fishermen, and biologists with an interest in this species will find the volume useful. It is available from the publisher in either softcover at $19.95 or hardbound at $24.95.

The McKernan Lectures: OCS Development and Extended Fishery Zones

The McKernan Lectures were established at the University of Washington, Seattle, in memory of Donald L. McKernan, first Director of the University's Institute for Marine Studies. Third in this series is **"Extended National Fisheries Jurisdiction, Palliative or Panacea?"** by Roy I. Jackson, former Assistant Director General (Fisheries) of the Food and Agriculture Organization, and before that Director, International North Pacific Fisheries Commission.

Jackson briefly reviews the beginnings of extended fisheries jurisdiction and its current status and effect on marine fisheries. Today, he says, nearly all marine fishery resources are under one or more national jurisdictions. He then outlines what extended jurisdiction means to such nations as Mauritania, Oman, and Canada, and to fisheries in the western and northeast Pacific Ocean. A summary reflects the author's views on world fisheries: Why fishery zone extensions happened so quickly, the need for regional international arrangements, and that good management of an exclusive fishing zone may entail more costs than its owner or its users or its resources can support. More than a palliative but less than a panacea, the author sees extended fisheries jurisdiction as having removed but one unknown from the complex and difficult equation of fisheries development.

The fourth lecture, **"Balancing Unknowns, A Decade of Controversy About Developing the Outer Continental Shelf,"** was presented by H. William Menard, former director of the U.S. Geological Survey and now professor of geology at Scripps Institution of Oceanography, La Jolla, Calif.

Menard reviews industry, scientific, and public interest in the development of OCS resources, the state of scientific information on OCS resources, economic benefits, and environmental costs, and discusses such controversial issues of the 1970's as on-structure drilling, leasing schedules and procedures, etc. He. concludes that OCS development "has the potential of helping solve our national energy problem with a smaller risk to the environment than any comparable alternative."

Both lectures, interesting and thought provoking discussions of timely marine topics, are available at $3.00 each from Washington Sea Grant Communications, 3716 Brooklyn Ave. N.E., Seattle, WA 98105.

A Handbook for Fishermen

The fourth edition of **"The Fisherman's Manual"** has been compiled, edited, and updated by the staff of *World Fishing*. The first 9 chapters are devoted primarily to trawlers, trawling, and related deck activities. Additional chapters deal with seine netting, purse seining, ring netting, fishing with light, set netting, line fishing (pole, troll, jigging, longlining), shellfishing, finding fish, care of the catch, deck machinery, ropes, knots and net mending, and handling the vessel. Well illustrated with drawings and photographs, the volume is a handy reference. The large-format ($8\frac{1}{4} \times 11\frac{1}{2}$ inches), 122-page softcover handbook is available from IPC Business Press (S&D) Ltd., Sundry Sales Department, Quadrant House, The Quadrant, Sutton, Surrey, England SM2 5AS for £10.

Editorial Guidelines for *Marine Fisheries Review*

Marine Fisheries Review publishes review articles, original research reports, significant progress reports, technical notes, and news articles on fisheries science, engineering, and economics, commercial and recreational fisheries, marine mammal studies, aquaculture, and U.S. and foreign fisheries developments. Emphasis, however, is on in-depth review articles and practical or applied aspects of marine fisheries rather than pure research.

Preferred paper length ranges from 4 to 12 printed pages (about 10-40 manuscript pages), although shorter and longer papers are sometimes accepted. Papers are normally printed within 4-6 months of acceptance. Publication is hastened when manuscripts conform to the following recommended guidelines.

The Manuscript

Submission of a manuscript to *Marine Fisheries Review* implies that the manuscript is the author's own work, has not been submitted for publication elsewhere, and is ready for publication as submitted. Commerce Department personnel should submit papers under completed NOAA Form 25-700.

Manuscripts must be typed (double-spaced) on high-quality white bond paper and submitted with two duplicate (but not carbon) copies. The complete manuscript normally includes a title page, a short abstract (if needed), text, literature citations, tables, figure legends, footnotes, and the figures. The title page should carry the title and the name, department, institution or other affiliation, and complete address (plus current address if different) of the author(s). Manuscript pages should be numbered and have 1½-inch margins on all sides. Running heads are not used. An "Acknowledgments" section, if needed, may be placed at the end of the text. Use of appendices is discouraged.

Abstract and Headings

Keep titles, heading, subheadings, and the abstract short and clear. Abstracts should be short (one-half page or less) and double-spaced. Paper titles should be no longer than 60 characters; a four- to five-word (40 to 45 characters) title is ideal. Use heads sparingly, if at all. Heads should contain only 2-5 words; do not stack heads of different sizes.

Style

In style, *Marine Fisheries Review* follows the "U.S. Government Printing Office Style Manual." Fish names follow the American Fisheries Society's Special Publication No. 6, "A List of Common and Scientific Names of Fishes from the United States and Canada," third edition, 1970. The "Merriam-Webster Third New International Dictionary" is used as the authority for correct spelling and word division. Only journal titles and scientific names (genera and species) should be italicized (underscored). Dates should be written as 3 November 1976. In text, literature is cited as Lynn and Reid (1968) or as (Lynn and Reid, 1968). Common abbreviations and symbols such as mm, m, g, ml, mg, and °C (without periods) may be used with numerals. Measurements are preferred in metric units; other equivalent units (i.e., fathoms, °F) may also be listed in parentheses.

Tables and Footnotes

Tables and footnotes should be typed separately and double-spaced. Tables should be numbered and referenced in text. Table headings and format should be consistent; do not use vertical rules.

Literature Citations

Title the list of references "Literature Citations" and include only published works or those actually in press. Citations must contain the complete title of the work, inclusive pagination, full journal title, the year and month and volume and issue numbers of the publication. Unpublished reports or manuscripts and personal communications must be footnoted. Include the title, author, pagination of the manuscript or report, and the address where it is on file. For personal communications, list the name, affiliation, and address of the communicator.

Citations should be double-spaced and listed alphabetically by the senior author's surname and initials. Co-authors should be listed by initials and surname. Where two or more citations have the same author(s), list them chronologically; where both author and year match on two or more, use lowercase alphabet to distinguish them (1969a, 1969b, 1969c, etc.).

Authors must double-check all literature cited; they alone are responsible for its accuracy.

Figures

All figures should be clearly identified with the author's name and figure number, if used. Figure legends should be brief and a copy may be taped to the back of the figure. Figures may or may not be numbered. Do not write on the back of photographs. Photographs should be black and white, 8- × 10- inches, sharply focused glossies of strong contrast. Potential cover photos are welcome but their return cannot be guaranteed. Magnification listed for photomicrographs must match the figure submitted (a scale bar may be preferred).

Line art should be drawn with black India ink on white paper. Design, symbols, and lettering should be neat, legible, and simple. Avoid freehand lettering and heavy lettering and shading that could fill in when the figure is reduced. Consider column and page sizes when designing figures.

Finally

First-rate, professional papers are neat, accurate, and complete. Authors should proofread the manuscript for typographical errors and double-check its contents and appearance before submission. Mail the manuscript flat, first-class mail, to: Editor, *Marine Fisheries Review*, Scientific Publications Office, National Marine Fisheries Service, NOAA, 7600 Sand Point Way N.E., BIN C15700, Seattle, WA 98115.

The senior author will receive 50 reprints (no cover) of his paper free of charge and 100 free copies are supplied to his organization. Cost estimates for additional reprints can be supplied upon request.

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